HIGH TEMPERATURE VACUUM BRAZING OF HARDENABLE CORROSION-RESISTANT PLASTIC MOLD STEELS

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High Temperature Vacuum Brazing of Hardenable Corrosion - Resistant Plastic Mold Steels

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• Introduction – Conformal Cooling and the HTVB- Processes
  • Stainless Plastic Mold Steels and Heat Treatment Parameters
  • High Temperature Vacuum Brazing of Stainless Plastic Mold Steels
  • Material Issues related to High Temperature Vacuum Brazing of Stainless Plastic Mold Steels
  • Summary & Conclusion
Introduction to the topic

- For **conformal cooling** of an injection mold, the cooling channels follow the cavity as close as possible.

- **Conformal cooling** of molds can increase productivity in plastic injection molding by reducing the process cycle time.

- Conformal cooling of molds can be realised by **additive manufacturing technologies**, e.g., selective laser melting, diffusion bonding and **high temperature vacuum brazing**.

- High temperature vacuum brazing is now widely used for non-corrosion resistant mold steels but not so frequently applied to **hardenable stainless mold steels**.

- In this presentation, some **important features** in **high temperature vacuum brazing of hardenable stainless mold steels** are highlighted.
### Conformal Cooling in Injection Molding

#### Available Additive Manufacturing Technologies - Pro´s & Con´s

<table>
<thead>
<tr>
<th>High Temperature Vacuum Brazing</th>
<th>Diffusion Bonding</th>
<th>Selective Laser Melting (SLM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build up with parting planes – very little degree of freedom in design, e.g. min. distance ~ 3 mm from border geometries, Smooth cooling channels Many suitable materials available</td>
<td>Build up with parting planes – little degree of freedom in design, Smooth cooling channels More suitable materials available Value creation in own tool shop</td>
<td>High degree of freedom in design and therefore high adjustability. Relatively rough cooling channels Limited choice of materials (e.g. 1.2709) Option for hybride technology</td>
</tr>
</tbody>
</table>

Source: Internet-Konstruktionsbüro Hein GmbH/D
High Temperature Vacuum Brazing of Hardenable Corrosion - Resistant Plastic Mold Steels

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**Hardenable Corrosion - Resistant - Mold Steels**

BOHLER Steel Grades involved in the presented project work – comparison to nearest standard grades:

<table>
<thead>
<tr>
<th>13 % Cr SS (wt. %)</th>
<th>C</th>
<th>Cr</th>
<th>Mn</th>
<th>Si</th>
<th>Others</th>
<th>Usual Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOHLER M333 ISOPLAST</td>
<td>0.24</td>
<td>13.25</td>
<td>0.35</td>
<td>0.2</td>
<td>N, Ni, Mo, V</td>
<td>48 -50 HRC</td>
</tr>
<tr>
<td>Mat. No. 1.2083</td>
<td>0.4</td>
<td>13</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>17 % Cr -1 % Mo SS (wt. %)</th>
<th>C</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Others</th>
<th>Usual Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOHLER M340 ISOPLAST</td>
<td>0.54</td>
<td>17.3</td>
<td>1.1</td>
<td>0.1</td>
<td>N</td>
<td>53 – 57 HRC</td>
</tr>
<tr>
<td>BOHLER M368 MICROCLEAN</td>
<td>0.54</td>
<td>17.3</td>
<td>1.1</td>
<td>0.1</td>
<td>N</td>
<td>53 – 57 HRC</td>
</tr>
<tr>
<td>AISI 440B (Mat.No. 1.4112)</td>
<td>0.9</td>
<td>17.5</td>
<td>1.1</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>20 % Cr- 1 % Mo - 4 %V SS (wt. %)</th>
<th>C</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
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<th>Usual Hardness</th>
</tr>
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<tbody>
<tr>
<td>BÖHLER M390 MICROCLEAN</td>
<td>1.9</td>
<td>20</td>
<td>1</td>
<td>4</td>
<td>W 0.6</td>
<td>56 -61 HRC</td>
</tr>
</tbody>
</table>

**ISOPLAST** – BOHLER - Protective Gas ESR –Process

**MICROCLEAN** – BOHLER Powder Metallurgy
Hardenable Corrosion - Resistant - Mold Steels

Heat Treatment of Steel Grades involved in the presented project work

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>Hardening</th>
<th>Temper</th>
</tr>
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<tbody>
<tr>
<td><strong>BOHLMEX M333</strong></td>
<td>980 - 1000 °C / fast quench, e.g. N2 (use 980°C for large molds)</td>
<td>Hold: 15 - 30 min.</td>
</tr>
<tr>
<td><strong>BOHLMEX M340</strong></td>
<td>980 - 1000 °C / fast quench, e.g. N2 (use 980°C for large molds)</td>
<td>Hold: 15 - 30 min.</td>
</tr>
<tr>
<td><strong>BOHLMEX M368</strong></td>
<td>1100 - 1180 °C / fast quench, e.g. N2</td>
<td>Hold: 20 - 30 min. (1100 - 1150°C)</td>
</tr>
</tbody>
</table>

Temper:
- 200 - 300 °C / min. 2 hrs / AC
- 3 x > 510 °C / min. 2 hrs / AC

Temper:
- ~ 300 °C / min. 2 hrs / AC
- 3 x > 520 °C / min. 2 hrs / AC

Special features:
- Specified optimum austenitizing temperatures
- Two tempering conditions specified → low tempering temperature for best corrosion resistance, high temper for large molds, dimensional stability, wear resistance
High Temperature Vacuum Brazing of Hardenable Corrosion - Resistant Plastic Mold Steels

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High Temperature Vacuum Brazing

Processes related to Corrosion Resistant Plastic Mould Steels

**High Temperature Brazing Processes**

- are combined heat treatment & joining processes
- need coordinated soldering and heat treatment temperatures & times
- have limited number of suitable bulk materials
- have limited number of suitable brazing filler metals

1050°C brazing process for M340 IP/M368 MC with 50 µm Ni-Cr-Si-B(L-Ni2) joining foil acc. to AMS 4777

Slow heating – controlled quenching after soldering process
High Temperature Vacuum Brazing

Brazing Filler Metal involved in the presented project work

**SAE AMS 4777** Rev. H
Nickel Alloy, Brazing Filler Metal
971 to 999 °C Solidus-Liquidus Range

Optimum, widely used brazing temperature @ 1050°C

(Composition similar to UNS N99620)

<table>
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<tr>
<th>Grade / wt. %</th>
<th>Ni</th>
<th>Si</th>
<th>Cr</th>
<th>B</th>
<th>Fe</th>
<th>C</th>
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<tr>
<td>AMS 4777</td>
<td>82</td>
<td>4.5</td>
<td>7.0</td>
<td>3.1</td>
<td>3.0</td>
<td>&lt; 0.06</td>
</tr>
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</table>

This filler metal has been used typically for joining nonferrous alloys and corrosion and heat-resistant steels and alloys where low flow point and corrosion and oxidation resistant joints with good strength at elevated temperatures are required, but usage is not limited to such applications.
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Material Issues related to corrosion Resistant Plastic Mould Steels

High Temperature Brazing Processes in many cases do not run in optimal temperature ranges for bulk material → compromise needed

**This missfit may cause:**

- different response to tempering (shift of T-t curve)
- coarse grain of bulk material (too high process temperature)
- detrimental precipitates in the joint as well as in transition zone and bulk material
- effect on corrosion resistance - especially when high Cr –Stainless Steels are involved

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**Vacuum heat treatment**

Hardening temperature:
- 1150°C
- 1070°C
- 1150°C and deep-freeze treatment

Tempering temperature 2x2h [°C]

**Microstructure**

To be discussed....
High Temperature Vacuum Brazing

Coarse grain in Bohler M333 ISOPLAST after HTVB @ 1050 °C, L-Ni2

Mould Insert - HTVB

Location of joint

Bulk material with ASTM GS # 4

→ Mould insert failed by stress (corrosion) cracking in service (leakage) due to coarse grain

→ Brazing Temperature must be in the range of **980 -1000°C** to avoid grain growth → use of different, more suitable soldering materials, e.g. Au82-Ni 950 or Ni-Fe alloys
High Temperature Vacuum Brazing

Response to temper after HTVB @ 1050°C of Bohler M390 MICROCLEAN

- Sample HTS@ 1050°C/NQ + 3 x temper @ 515°C
- Sample HTS@ 1050°C/NQ + cryo + 3 x temper @ 200°C

Austentization @1050°C not optimal for M390MC (recommendation 1100 - 1180 °C)

- lower hardness level achieved (54 - 56 HRC)
- may cause unfavourable carbide transformation - significant effects observed in diffusion zone of test samples but not in bulk material

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High Temperature Vacuum Brazing

Material aspects in HTVB of hardenable SS with L-Ni2 @ 1050°C

- Formation of Boron-rich precipitates in the joining area and in transition zone
- Formation of GB-Cr-Carbides in the diffusion zone

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<th>%</th>
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<th>Fe</th>
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<tr>
<td>Foil 50µm</td>
<td>3</td>
<td>&lt;0.06</td>
<td>4.5</td>
<td>7</td>
<td>3</td>
<td>Rem.</td>
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Effect on Corrosion Resistance?
High Temperature Vacuum Brazing

Corrosion Resistance after HTVB @ 1050°C with L-Ni2

EC-corrosion test in artificial seawater @ pH 4.0, room temperature (AVESTA – ECP-cell)

M368 MC, High Temperature soldering, cryogenic treatment & tempered

cryo-treatment(-70°C) + 3x 530°C  
cryo-treatment(-70°C) + 3x 300°C

Bulk material

Joining area

Current density μA/cm²

-300 -250 -200 -150 -100 -50 0 50 100 150 200

-100 -50 0 50 100 150 200

10⁻² A/cm²

10⁻⁴ A/cm²

Potential mV

Testing area

Joint

Note:
Specimen tempered @ 530°C → free of retained austenite
Specimen tempered @ 300°C → ~ 3 % ret. austenite

Lower pitting potential → better corrosion resistance
High Temperature Vacuum Brazing

Corrosion Resistance after HTVB @ 1050°C with L-Ni2

EC-corrosion test in artificial seawater @ $p_H 4,0$, room temperature (AVESTA –ECP-cell)

M390 MICROCLEAN
- Corrosion resistance of bulk material better than of material containing the joint
- Low tempering temperature always results in better corrosion resistance

M390 MICOCLEAN - HTS @1050°C, N-quench + tempered (joining material L-Ni2)

Note: All specimens free of retained austenite
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Summary & Conclusion

- Bohler Plastic Mold steels are strongly involved in manufacturing of mold inserts with conformal cooling, e.g. High Temperature Vacuum Brazing.

- Depending on the mold material and the brazing filler metal selected, the process parameters of HTVB are always a compromise and may affect properties of the components made of hardenable corrosion-resistant plastic mold steels.

Aspects discussed in Detail →

- M333 IP should not be joined at temperatures higher than rec. $T_A$ e.g. 980 -1000°C due to risk of coarse grain → use adequate joining metal (e.g. Au based).

- M368 MC, M340 IP and M390 MC can be joined successfully with L-Ni2 @ 1050°C. → consider shift of tempering curve for hardness specification.

- Precipitates in joining zone and diffusion zone can not be avoided. M368 MC and M340 IP show no effect on corrosion resistance. M390 MC shows reduced corrosion resistance in joining area.