Welcome

Mr. Andrew G. Kireta, Sr.
President & CEO
Copper Development Association Inc.
Die Casting Background

Dr. Dale T. Peters
Consultant
Copper Development Association Inc.
Introduction

Program initiation - Background

- Development encouraged by motor manufacturers
- Program members include:
  - Motor manufacturers
  - Die-cast equipment manufacturers
  - Mold materials suppliers
  - Copper industry technical & financial support
- Members all contributing to process development
Participants

- CDA—program management & technical direction
- ICA—major copper industry support
- US Dept. of Energy—NICE^3/OIT contributed $425,000
- Motor Manufacturers (multiple)
- Air Conditioning & Refrigeration Institute
- CDA Members—alloy testing suggestions
- Formcast—die casting/technology capability
Objectives

- Development of mold (die) materials and processing for cost-effective copper motor rotor manufacturing
- Electrical energy efficiency improvement
Multiple analyses show additional 15% to 20% reduction in motor losses (input/output method) achievable with copper rotor compared to same motor design using aluminum.
Introduction

Advantages to motor performance - scenarios for manufacturers and users

- Improvement in motor electrical energy efficiency to reduce user operating costs
- Reduction in overall premium motor manufacturing cost at existing efficiency
- Reduction in potential motor weight
Introduction

Options for improvement in motor energy efficiency in operation

- Create a “super”- premium efficiency motor product line
- Improve existing motor efficiency without major re-engineering by replacing current aluminum with copper rotor
Problem with common mold materials:

- High temperature
- Substantial latent heat
- Thermal shock
- Thermal fatigue (heat checking)
- High operating temperature: Loss of strength
- In previous studies: tool steel molds lasted only a few shots
Die filled with liquid Copper $t = \text{initial}$

Dwell time: Cu solidifying $t = 1.5 \text{ minutes}$

Cu separated from die $t = 2.0 \text{ minutes}$

Cu casting removed $t = 2.5 \text{ minutes}$

Cracking – Thermal Expansion & Contraction
Die Materials Testing

Insert die sets used in material evaluations
Die Materials Testing

H-13 tool steel die cavity insert tool set
Die Materials Testing

Test cavity design & first copper die casting
Thermal Modeling

Modeling studies

Temperature profiles in H-13 die inserts during cooling cycle
solidified fraction
Mold Material: Tungsten
Initial Wall Temperature: 650°C
Shot Temperature: 1200°C
Post Fill Setting Time: 4 sec
Mold/Copper Resistance: 1°C cm²/watt in Runners etc.
Mold/Copper Resistance: 1/40°C cm²/watt in Gate (Fluid Boundary Layer)
Predicted Temperature Profiles

Mold/Copper Contact Resistance = 0.3°C·cm²/Watt

THERMOCOUPLE (°C)

TIME (seconds)

Series 1
Series 2
Series 3
Actual Temperature Profiles
The Die Casting Process

System design at Formcast test facility

- 660 metric-ton Buhler SC (independent computer controlled - closure & shot)

- Induction melting (15 kg of copper in 9 minutes for rotors – earlier design used 4 kg of copper per 2 minute cycle for material testing)

- High-temperature mold (die) materials and handling to achieve long life-in-service
The Die Casting Process

Bühler horizontal die caster
The Die Casting Process

Inductotherm induction furnace
The Die Casting Process

Die halves – H-13 tool steel
The Die Casting Process

Applying dry film lubricant
The Die Casting Process

Measuring copper charge
The Die Casting Process

Transferring molten copper to shot sleeve
The Die Casting Process

Pouring copper into shot sleeve
The Die Casting Process

Ejecting copper casting and runner
The Die Casting Process

Extracting die cast copper
Testing Die Materials

Dr. John G. Cowie
Vice President
Copper Development Association Inc.
Testing of Die Materials – H-13 Steel

First Casting Trial:

H-13 Steel Dies
Baseline Data
Testing of Die Materials – H-13 Steel

Visual Examination – Thermal Fatigue Cracks

Shot # 9          Shot # 800
Testing of Die Materials – H-13 Steel

Macrostructure of die cast copper
Testing of Die Materials – H-13 Steel

Microstructure of die cast copper near gate region
Testing of Die Materials – H-13 Steel

Microstructure of die cast copper
## Testing of Die Materials – H-13 Steel

### Iron & Oxygen Contamination

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>Iron Content ppm</th>
<th>Oxygen Content wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>17</td>
<td>0.059</td>
</tr>
<tr>
<td>11</td>
<td>350</td>
<td>0.11</td>
</tr>
<tr>
<td>438</td>
<td>56</td>
<td>0.15</td>
</tr>
<tr>
<td>600</td>
<td>61</td>
<td>0.057</td>
</tr>
<tr>
<td>800</td>
<td>10</td>
<td>0.055</td>
</tr>
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</table>
## Testing of Die Materials – H-13 Tool Steel

### Conductivity

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>% IACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>97.8</td>
</tr>
<tr>
<td>11</td>
<td>95.2</td>
</tr>
<tr>
<td>438</td>
<td>96.8</td>
</tr>
<tr>
<td>600</td>
<td>99.7</td>
</tr>
<tr>
<td>800</td>
<td>99.4</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>98.8</strong></td>
</tr>
</tbody>
</table>

Average % IACS: 98.8
Testing of Die Materials – H-13 Steel

Alternative Shot Sleeves

- Liner insert below pouring hole
- Reduced erosion & wear
- Reduced contamination of copper
- Retained electrical conductivity in cast copper
- Remelting runners and gates sections
Second Casting Trial:

Chemical Vapor Deposition (CVD) Tungsten Coated on TZM Modified Molybdenum Dies
Testing of Die Materials – CVD-W on TZM

CVD tungsten

After 50 shots, cracking from ejector pin holes and heat-checking. Preheated 350 C.
Third Casting Trial:

Nickel Alloy Dies -

617
718
MA-754
Testing of Die Materials – Inconel

Visual examination

Preheat 320°C to 410°C

Shot # 50

Shot # 235
### Alloy comparison

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Heat Checking Observed</th>
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<tbody>
<tr>
<td>MA 754</td>
<td>Shot# 50</td>
</tr>
<tr>
<td>718</td>
<td>Shot# 100</td>
</tr>
<tr>
<td>617</td>
<td>Shot# 200 (minor crazing)</td>
</tr>
</tbody>
</table>
Testing of Die Materials – Inconel

Porosity
Testing of Die Materials – Inconel

Electrical conductivity

<table>
<thead>
<tr>
<th>Shot Number</th>
<th>% IACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>99.4</td>
</tr>
<tr>
<td>150</td>
<td>99.1</td>
</tr>
<tr>
<td>235</td>
<td>101.2</td>
</tr>
<tr>
<td>Average</td>
<td>99.9</td>
</tr>
</tbody>
</table>
Testing of Die Materials – TZM & Anviloy

Fourth Casting Trial:

TZM & Anviloy Dies
TZM & Anviloy dies

 TZM (molybdenum alloy)
  Oxidized at die operating temperatures

 Anviloy (tungsten alloy)
  Brittle below 450C
  Difficult to machine
Testing of Die Materials – TZM & Anviloy

Anviloy dies

- Moving half
- Preheat 450C to 560C
Fifth Casting Trial:

Nickel Alloy Dies 617 & 625 at Elevated Temperature
Testing of Die Materials – Nickel Alloys #2

Inconel Alloy Dies at Elevated Temperature

- After 950 shots, minor cracking
- Preheat 560°C to 660°C
Multiple high-temperature mold (die) materials may perform adequately in various die locations—depending upon thermal stresses/load requirements.

Mold (die) material handling—preheat requirements are critical—to reduce thermal stresses and assure long die-life in-service.
### Nickel-based superalloy compositions (wt.%)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Ni</th>
<th>Co</th>
<th>Cr</th>
<th>Mo</th>
<th>W</th>
<th>Fe</th>
<th>Al</th>
<th>C</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>230</td>
<td>Bal.</td>
<td>5*</td>
<td>22</td>
<td>2</td>
<td>14</td>
<td>3*</td>
<td>0.3</td>
<td>0.1</td>
<td>0.4 Si, 0.5 Mn, 0.02 La</td>
</tr>
<tr>
<td>617</td>
<td>Bal.</td>
<td>12.5</td>
<td>22</td>
<td>9</td>
<td>-</td>
<td>1.5</td>
<td>1.2</td>
<td>0.07</td>
<td>0.30 Ti</td>
</tr>
<tr>
<td>625</td>
<td>Bal.</td>
<td>1*</td>
<td>21</td>
<td>9</td>
<td>-</td>
<td>5*</td>
<td>0.4*</td>
<td>0.1*</td>
<td>0.4* Ti, 0.5 Mn 3.7 Nb+Ta</td>
</tr>
</tbody>
</table>

* maximum
## Die Materials Testing

### Superalloy comparison – 0.2% YS (MPa)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>20°C</th>
<th>540°C</th>
<th>650°C</th>
<th>760°C</th>
<th>870°C</th>
<th>980°C</th>
<th>1100°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>230</td>
<td>393</td>
<td>276</td>
<td>269</td>
<td>283</td>
<td>221</td>
<td>124</td>
<td>57</td>
</tr>
<tr>
<td>617</td>
<td>352</td>
<td>228</td>
<td>214</td>
<td>221</td>
<td>214</td>
<td>110</td>
<td>55</td>
</tr>
<tr>
<td>625</td>
<td>490</td>
<td>372</td>
<td>372</td>
<td>345</td>
<td>207</td>
<td>83</td>
<td>39</td>
</tr>
</tbody>
</table>
## Superalloy comparison – UTS (MPa)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>20°C</th>
<th>540°C</th>
<th>650°C</th>
<th>760°C</th>
<th>870°C</th>
<th>980°C</th>
<th>1100°C</th>
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</thead>
<tbody>
<tr>
<td>230</td>
<td>862</td>
<td>710</td>
<td>669</td>
<td>586</td>
<td>400</td>
<td>228</td>
<td>117</td>
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<tr>
<td>617</td>
<td>759</td>
<td>593</td>
<td>565</td>
<td>503</td>
<td>352</td>
<td>200</td>
<td>110</td>
</tr>
<tr>
<td>625</td>
<td>903</td>
<td>772</td>
<td>759</td>
<td>600</td>
<td>345</td>
<td>166</td>
<td>97</td>
</tr>
</tbody>
</table>
### Superalloy comparison – % elongation

<table>
<thead>
<tr>
<th>Alloy</th>
<th>20°C</th>
<th>540°C</th>
<th>650°C</th>
<th>760°C</th>
<th>870°C</th>
<th>980°C</th>
<th>1100°C</th>
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</thead>
<tbody>
<tr>
<td>230</td>
<td>48</td>
<td>56</td>
<td>55</td>
<td>46</td>
<td>59</td>
<td>71</td>
<td>50</td>
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<tr>
<td>617</td>
<td>58</td>
<td>64</td>
<td>69</td>
<td>56</td>
<td>54</td>
<td>64</td>
<td>50</td>
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<tr>
<td>625</td>
<td>49</td>
<td>54</td>
<td>56</td>
<td>53</td>
<td>46</td>
<td>44</td>
<td>45</td>
</tr>
</tbody>
</table>
Die Materials Testing

Conclusions – Phase I of study

- Five copper die casting trials completed
- Inconel alloy 617 best candidate tested
- Haynes alloy 230 alternate die material
- Must run dies hot: 650C
- Copper microstructure exhibited minor defects
- Conductivity very good
- Elimination of iron in system should improve conductivity
- Reduction of oxygen contamination should improve ductility
Rotor Die Casting

Dr. Edwin Brush (Ned)
Consultant
BBF & Associates
Die Casting Copper Rotors

Master die set for casting rotors

Ejector Section

Center Section

Stationary Section

Alternate (Thick) Center Section
Die Casting Copper Rotors

Larger Induction melting furnace

Inductotherm
Die Casting Copper Rotors

Die cavity inserts — gates and runner
Die Casting Copper Rotors

Arbor (Mandrel)
Die Casting Copper Rotors

Core stack being assembled
Die Casting Copper Rotors

Assembled core stacks
Die Casting Copper Rotors

Compressing laminations
Die Casting Copper Rotors

Inserting laminations (core stack)
Die Casting Copper Rotors

Inductotherm (Induction melting) furnace
Die Casting Copper Rotors

Copper pellets melting in the crucible
Die Casting Copper Rotors

Removing crucible from furnace
Die Casting Copper Rotors

Pouring copper into the shot sleeve
Die Casting Copper Rotors

Programming computer controlled die-caster
Die Casting Copper Rotors

Ejecting rotor with runner
Die Casting Copper Rotors

Extracting rotor
Die Casting Copper Rotors

Water-quenching rotor
Die Casting Copper Rotors

Fin detail - complete fill on a large rotor
Die Casting Copper Rotors

Cross-section of a cast copper rotor
Rotor die-casting

- Rotor die casting evaluation runs for four motor companies completed
- Evaluation of prototype motor performance - three sets of results (next)
- Run of 200 to 500 rotors for production motors planned
Rotor Steel Specification for Copper

Recommend Review of Current Specifications Developed for Aluminum Die Casting

Indications to Date:

- High temperature anneals, utilized in many “larger” rotors, appear NOT affected –
- No increases in losses observed (IEEE Tests)

- Low temperature anneals, utilized in some “smaller” rotors, appear affected
- Increases in core (Iron) losses observed
Target for Opportunity

Advantages to motor performance - scenarios for manufacturers and users

- Improvement in motor electrical energy efficiency to reduce user operating costs
- Reduction in overall premium motor manufacturing cost at existing efficiency
- Reduction in potential motor weight
System design at Formcast test facility

- 660 metric-ton Buhler SC (independent computer controlled - closure & shot)
- Induction melting (15 kg of copper in 9 minutes for rotors – earlier design used 4 kg of copper per 2 minute cycle for material testing)
- High-temperature mold (die) materials and handling to achieve long life-in-service
wall temperature contours
Motor Test Results

Mr. Darryl Van Son
Consultant
Copper Development Association Inc.
Two-thirds (2/3) of all industrial electricity is used to run motors.
Motors use 680 Billion kW-Hr per year.

1% better motor efficiency would save:

- 6.8 Billion kW-Hr per year
- $US 500 Million at 7 cents per kW-Hr
- Equivalent to 13 Million barrels of oil
**Diminishing Returns**

- **Losses**
- **Costs to Further Reduce Losses**

We are here

![Graph showing diminishing returns with Time on the x-axis and Costs on the y-axis. The graph illustrates the principle that as costs increase, losses decrease, reaching a point where further reductions in costs lead to diminishing returns.]
## Motor Tests

<table>
<thead>
<tr>
<th>HP</th>
<th>kW</th>
<th>Poles</th>
<th>Efficiency</th>
<th>Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Al</td>
<td>Cu</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
<td>83.2</td>
<td>86.4</td>
</tr>
<tr>
<td>7.5</td>
<td>5.5</td>
<td>4</td>
<td>74.0</td>
<td>79.0</td>
</tr>
<tr>
<td>10</td>
<td>7.5</td>
<td>4</td>
<td>85.0</td>
<td>86.5</td>
</tr>
<tr>
<td>15</td>
<td>11</td>
<td>4</td>
<td>89.5</td>
<td>90.7</td>
</tr>
<tr>
<td>25</td>
<td>19</td>
<td>4</td>
<td>90.9</td>
<td>92.5</td>
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<tr>
<td>40</td>
<td>30</td>
<td>4</td>
<td>88.8</td>
<td>90.1</td>
</tr>
<tr>
<td>120</td>
<td>90</td>
<td>2</td>
<td>91.4</td>
<td>92.8</td>
</tr>
<tr>
<td>270</td>
<td>200</td>
<td>4</td>
<td>92.0</td>
<td>93.0</td>
</tr>
</tbody>
</table>

Average: 14.7%
# Motor Tests

## Rotor $I^2R$ Losses (Watts)

<table>
<thead>
<tr>
<th>HP</th>
<th>kW</th>
<th>Poles</th>
<th>Al</th>
<th>Cu</th>
<th>Difference</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
<td>221</td>
<td>92</td>
<td>129</td>
<td>-58%</td>
</tr>
<tr>
<td>5</td>
<td>3.7</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-38%</td>
</tr>
<tr>
<td>15</td>
<td>11</td>
<td>4</td>
<td>262</td>
<td>157</td>
<td>104</td>
<td>-40%</td>
</tr>
<tr>
<td>25</td>
<td>19</td>
<td>4</td>
<td>410</td>
<td>292</td>
<td>118</td>
<td>-40%</td>
</tr>
</tbody>
</table>
### Motor Tests

## Temperature Rise

<table>
<thead>
<tr>
<th></th>
<th>AI</th>
<th>Cu</th>
<th>Difference</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 HP (11kW) Motor</td>
<td>64.9C</td>
<td>59.5C</td>
<td>- 4.5C</td>
<td>- 7%</td>
</tr>
<tr>
<td>25 HP (18.5 kW) Motor</td>
<td>79.9C</td>
<td>47.2C</td>
<td>- 32.7C</td>
<td>- 41%</td>
</tr>
</tbody>
</table>

- Affects life expectancy of the motor
- For every 10 degrees C hotter a motor runs, life can be reduced in half
- Copper rotors could increase life expectancy
- Similar results have been seen in premium efficiency motors since their introduction 20 years ago
Copper rotor motors averaged 90.7% efficiency
Range: 90.6% – 90.8%

Copper rotor losses averaged 157 Watts
Range: 153 Watts – 167 Watts

Stray load losses were down 23%

Process variables tested had no predictable affect on final test results

No balancing weights were required

This is a very robust process with consistency not seen in current rotor die casting methods
Motor Tests

Motor designed around a copper rotor

Tests of an “optimized” copper motor

- Rotor losses: - 40%
- Total losses: - 23%
- Temperature rise: - 41%
- Efficiency: + 1.6% 90.9% vs. 92.5%

Stator windings and iron core were modified from standard motor design to gain best possible results
**Motor Tests**

**Rotor Cost Implications**

- Example: 15 HP (11 kW), +1.2% Efficiency
- Rotor conductive material cost: $4 Al, $14 Cu
- Melt energy & die insert amortization: $1.30
- Motor list price range: $900 - $1500
- User payback measured in months
- Adjusting cost of other factors like stack and heat control can offset material cost
- One manufacturer reduced total motor cost 7% (average of many ratings)
**Motor Tests**

**Additional Implications**

- Higher efficiency in the same stack length
- Same efficiency in a reduced stack length
  - Offsetting material cost differences
- Some combination in between
- Minimize balancing requirements
- Elimination of “safety factor” extra stack length
  - to compensate for rotor irregularities
15 kW Motor - Past, Present and Future

Nameplate Efficiency (in Percent)

<table>
<thead>
<tr>
<th>87</th>
<th>88</th>
<th>89</th>
<th>90</th>
<th>91</th>
<th>92</th>
<th>93</th>
<th>94</th>
<th>95</th>
<th>96</th>
<th>97</th>
<th>98</th>
<th>99</th>
<th>100</th>
</tr>
</thead>
</table>

- Nirvana
- Super Conducting
- Amorphous Steel Laminations
- Potential Copper Rotor
- Today’s Premium Efficiency
- 1997 Energy Policy Act
- Today’s “Standard” Motor
- Historic – 1975

15 kW Motor - Past, Present and Future
Die Design

Mr. Ruedi Beck
DieTec GmbH
Die Designer
Info@dietec.ch
Principles of die casting technology

Cold chamber

Diagram showing the process of die casting, including the cold chamber stage.
Cold chamber technology

1st phase

The metal is slowly brought up to the gate, according to shot volume and procedure 1-4 s
### Abbreviations for die casting

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
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<tbody>
<tr>
<td>A</td>
<td>area</td>
<td>[mm²]</td>
</tr>
<tr>
<td>Aₖ</td>
<td>runner area</td>
<td>[mm²]</td>
</tr>
<tr>
<td>A₈M</td>
<td>projected area</td>
<td>[mm²]</td>
</tr>
<tr>
<td>dₘ</td>
<td>plunger diameter</td>
<td>[cm²]</td>
</tr>
<tr>
<td>FₐLI</td>
<td>opening force</td>
<td>[mm]</td>
</tr>
<tr>
<td>F₈LN</td>
<td>closing force</td>
<td>[kN]</td>
</tr>
<tr>
<td>%F</td>
<td>filling rate</td>
<td>[%]</td>
</tr>
<tr>
<td>l₈Maktiv</td>
<td>active shot length</td>
<td>[mm]</td>
</tr>
<tr>
<td>mₐ</td>
<td>weight after gate</td>
<td>[g]</td>
</tr>
<tr>
<td>m₁</td>
<td>shot weight</td>
<td>[g]</td>
</tr>
<tr>
<td>mₚₜart</td>
<td>part weight</td>
<td>[g]</td>
</tr>
<tr>
<td>mₜoverflow</td>
<td>overflow weight per part</td>
<td>[g]</td>
</tr>
<tr>
<td>mₘrunner</td>
<td>runner weight</td>
<td>[g]</td>
</tr>
<tr>
<td>n</td>
<td>number of cavity</td>
<td>[ ]</td>
</tr>
<tr>
<td>p₈1ₜₐ₅M</td>
<td>final casting pressure</td>
<td>[bar]</td>
</tr>
<tr>
<td>Qₘ</td>
<td>flow rate</td>
<td>[cm³/s]</td>
</tr>
<tr>
<td>Sₐ</td>
<td>gate section</td>
<td>[mm²]</td>
</tr>
<tr>
<td>SₜV</td>
<td>venting area</td>
<td>[mm²]</td>
</tr>
<tr>
<td>tₕ</td>
<td>filling time</td>
<td>[s]</td>
</tr>
<tr>
<td>Vₐ</td>
<td>volume after gate</td>
<td>[cm³]</td>
</tr>
<tr>
<td>vₙC</td>
<td>plunger speed</td>
<td>[m/s]</td>
</tr>
<tr>
<td>vₘₐ</td>
<td>gate velocity</td>
<td>[m/s]</td>
</tr>
</tbody>
</table>
**Gate technology**

Gate area $S_A$

$$S_A = \frac{V_A}{V_{MA} \cdot t_F} = \frac{m_A}{V_{MA} \cdot t_F}$$

$$m_A = n \cdot (m_{\text{part}} + m_{\text{overflow}})$$

Example:

- $m_{\text{part}} = 450 \text{ g}$
- $m_{\text{overflow}} = 20 \text{ g}$
- $m_{\text{runner}} = 1450 \text{ g}$
- $v_{MA} = 45 \text{ m/s}$
- $t_F = 0.05 \text{ s}$
- $?= 2.5 \text{ g/ cm}^3$
Gate velocity $v_{MA}$

$V_{MA} = \underline{\quad} \quad V_{MA} = \underline{\quad}$

**Aluminum**
- 20 ... 60 m/s Standard
- 15 ... 30 m/s Vacuum

**Zinc**
- 30 ... 50 m/s Standard

**Copper**
- 30 ... 45 m/s Standard
**Filling time** $t_F$

<table>
<thead>
<tr>
<th>$s$ [mm]</th>
<th>$t_F$ [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>10 ... 30</td>
</tr>
<tr>
<td>1.8</td>
<td>20 ... 40</td>
</tr>
<tr>
<td>2.0</td>
<td>20 ... 60</td>
</tr>
<tr>
<td>2.3</td>
<td>30 ... 70</td>
</tr>
<tr>
<td>2.5</td>
<td>40 ... 90</td>
</tr>
<tr>
<td>3.0</td>
<td>50 ... 100</td>
</tr>
<tr>
<td>3.8</td>
<td>50 ... 120</td>
</tr>
<tr>
<td>5.0</td>
<td>60 ... 200</td>
</tr>
</tbody>
</table>
Metal flow rate \( Q_m \)

\[
Q_M = \frac{m_A}{? \cdot t_F}
\]

\[
\begin{align*}
\text{m}_{\text{part}} &= 450 \text{ g} \\
\text{m}_{\text{overflow}} &= 20 \text{ g} \\
\text{m}_{\text{runner}} &= 1450 \text{ g} \\
\text{v}_{\text{MA}} &= 45 \text{ m/s} \\
\text{t}_F &= 0.05 \text{ s} \\
? &= 2.5 \text{ g/ cm}^3
\end{align*}
\]
Venting area; \( S_V \)

\[
S_V \ ? \ \frac{Q_M}{200 \ \frac{m}{s}}
\]

It means:

\[
Q_M \ ? \ \frac{m_A}{t_F}
\]

Example:

\[
\begin{align*}
m_{\text{part}} &= 450 \text{ g} \\
m_{\text{overflow}} &= 20 \text{ g} \\
m_{\text{runner}} &= 1450 \text{ g} \\
v_{\text{MA}} &= 45 \text{ m/s} \\
t_F &= 50 \text{ ms} \\
r &= 2.5 \text{ g/ cm}^3
\end{align*}
\]
Runner cross section $A_k$

$A_k = 1.6 \ldots 2.2 \times S_A$

$C_B = 1.5 \ldots 2.5 \times C_T$

$A_k = C_B \times C_T - C_T \times 2 \times \tan (15^\circ)$

$A_k = C_B \times C_T - C_T \times 2 \times 0.27$
Die temperature: Heat transfer

Heat Conduction:
Heat transport inside a substance.

*Example: Machine plate*

Convection:
Heat transfer from a liquid substance to a solid substance or turned back.

*Example: Steel on cooling water*

Radiation:
Heat transfer through electromagnetic radiation.

*Example: Die frame on the air*
Sankey diagram
Supplied heat quantity for copper

\[
Q_{zu} = m_l \ast c_p \ast (T_{In} - T_{Ej}) + C \ast m_l
\]

- \(Q_{zu}\) supplied heat quantity [kJ]
- \(m_l\) shot weight [kg]
- \(c_p\) specific heat [kJ/kgK] \(c_{pCu} = 0.394\) kJ/kgK
- \(T_{In}\) metal temperature on filling [K]
- \(T_{Ej}\) metal temperature on ejection [K]
- \(C\) heat of fusion [kJ/kg] \(C_{Cu} = 172\) kJ/kg

Example:

\[
ml = 1.2\ \text{kg} ; \quad T_{IN} = 1473\ K ; \quad T_{Ej} = 1123\ K
\]

\[
Q_{ZU} = 1.2 \ast 0.394 \ast (1473 - 1123) + 172 \ast 1.2 = 371.9\ \text{kJ}
\]

\[
1000\ \text{cm}^3 \quad \Rightarrow \quad 1.7 \ast Q_{Al} = Q_{Cu}
\]
Heat Conduction \( Q_l \)

\[
Q_l = \ ?_w \times A_w \times (T_{Ob} - T_{Med}) / s
\]

- \( Q_l \) [kJ]
- \( ?_w \) Conductivity of the tool [W/mK]
- \( s \) The distance of the temperature canal from the cavity [m]
- \( A_w \) The effective cross-section area of the tool [m\(^2\)]
- \( T_{Ob} \) The middle surface temperature [K]
- \( T_{med} \) The middle wall temperature on the thermal fluid medium [K]

Example: Conductivity of the steels

- \( ?_w \) 1.1730 \( \times \) 50 W / mK
- 1.2343 \( \times \) 15 W / mK
- Cu 350 W / mK
Heat radiation $Q_{St}$

$$Q_{St} = A_{DGW} \times ? \times C_S \times (T_{WO}^4 - T_{UM}^4)$$

$A_{DGW}$ = Contact face of the die to the surrounding air [m$^2$]

$? = $ Emissions degree

$C_S = $ Stefan-Boltzmann-constant for the black body

$5.67 \times 10^{-8} \text{ W} / \text{m}^2\text{K}^4$

$T_{WO}$ = Surface temperature of the die [K]

$T_{UM}$ = Surrounding temperature [K]

**Example: Emissions degree of steel**

<table>
<thead>
<tr>
<th>$?$</th>
<th>steel bright grinded</th>
<th>0.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>steel little rusty</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>steel strong rusty</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

(values at 293 K)
The three cooling areas
Thermal expansion

dL 100°C / 100 mm = 0.12 mm

1250°C Cu
980°C
885°C
650°C
300°C

25

100
## Overview of Thermal Insulation and Engineering Materials

### Thermal Insulation Materials

<table>
<thead>
<tr>
<th>Grades</th>
<th>Thermal stability in °C</th>
<th>Compressive strength at ambient temperature in N/mm² DIN 53 453</th>
<th>Compressive strength at 200°C in N/mm² DIN 53 453</th>
<th>Thermal conductivity W/mK at ambient temperature DIN 52 617</th>
<th>Water absorption in % / 24 hours DIN 53 496</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal Insulation Boards</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S 4000</td>
<td>200</td>
<td>300</td>
<td>100</td>
<td>0.13</td>
<td>0.10</td>
</tr>
<tr>
<td>BRA-CI A N</td>
<td>210</td>
<td>600</td>
<td>290</td>
<td>0.30</td>
<td>0.20</td>
</tr>
<tr>
<td>BRA-GLA HT</td>
<td>220</td>
<td>600</td>
<td>400</td>
<td>0.30</td>
<td>0.05</td>
</tr>
<tr>
<td>BRA-GLA VT</td>
<td>230</td>
<td>660</td>
<td>430</td>
<td>0.30</td>
<td>0.05</td>
</tr>
<tr>
<td>BRA-GLA VP</td>
<td>240</td>
<td>600</td>
<td>400</td>
<td>0.30</td>
<td>0.05</td>
</tr>
<tr>
<td>KV 3</td>
<td>240</td>
<td>600</td>
<td>400</td>
<td>0.25</td>
<td>0.075</td>
</tr>
<tr>
<td>GL-M</td>
<td>300</td>
<td>400</td>
<td>260</td>
<td>0.30</td>
<td>&lt; 0.10</td>
</tr>
<tr>
<td>CI-P</td>
<td>350</td>
<td>320</td>
<td>240</td>
<td>0.31</td>
<td>&lt; 0.10</td>
</tr>
<tr>
<td><strong>Side Insulation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S 2000 A</td>
<td>200</td>
<td>100</td>
<td>70</td>
<td>0.10</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>BRA-H FX</td>
<td>200</td>
<td>-</td>
<td>1</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Compensating Inlay</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AL 2000 N</td>
<td>200</td>
<td>max. 300</td>
<td>max. 150</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Special Grade</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BRA-CI A Special</td>
<td>230</td>
<td>600</td>
<td>380</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISOFLEX AFV</td>
<td>825</td>
<td>-</td>
<td>-</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Flexline</td>
<td>260</td>
<td>-</td>
<td>-</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>
Insulation material

Brandenburger materials enable a comprehensive thermal insulation for moulds and tools in injection moulding industries.

Following possibilities of application and resulting advantages mainly characterize our products:

- **S 4000 and BRA-GLA Grades**
  ... compression- and dimensionally stable thermal insulation at the clamping area in order to avoid effectively heat contacts with the machine.

- **S 2000 A Grade**
  ... insulation with reflective properties on exterior surfaces, especially for large moulds and exposed heat surfaces. The profiled finish forms small hollow chambers, such as those in foam structures, and increases the degree of insulation provided.

- **BRA-GLA VP Grade**
  ... compression- and dimensionally stable thermal insulation in hot runner manifolds.

- **Flexline und BRA-FLEX Grades**
  ... for equipment using hot water, steam and temperature-controlled oil lines (Flexline) as well as exposed heating platen surfaces with flexible, oil-resistant insulation (ERA-FLEX).

Photo: Injection moulding tool with Brandenburger thermal protection system
# Insulation material

<table>
<thead>
<tr>
<th>Grades</th>
<th>Thermal stability in °C</th>
<th>Compressive strength at ambient temperature in N/mm² EN ISO 604</th>
<th>Compressive strength at 200 °C in N/mm² EN ISO 604</th>
<th>Thermal conductivity W/mK at ambient temperature DIN 52 612</th>
<th>Water absorption in % / 24 hours DIN 53 495</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supratherm T</td>
<td>500</td>
<td>100</td>
<td>75</td>
<td>0.32</td>
<td>max. 15</td>
</tr>
<tr>
<td>Supratherm HT 4</td>
<td>850</td>
<td>15</td>
<td>10</td>
<td>0.09</td>
<td>85</td>
</tr>
<tr>
<td>Supratherm HT 175</td>
<td>1000</td>
<td>34</td>
<td>30</td>
<td>0.22</td>
<td>20</td>
</tr>
</tbody>
</table>
Selected Brandenburger High Temperature Insulation Materials

The outstanding attributes of the Suprterm grades are above all, the resistance to high temperatures up to 1000 °C, the very good thermal insulation, the noncombustibility, long application life and the ability to withstand aggressive gases in firing plants.

**Suprtherm T Grade**

This tightly compressed fibre-cement material is especially suited as asbestos substitute.

**Suprtherm HT 4 Grade**

This low compressed silicate fibre material can withstand high temperatures. Application temperatures are in the range up to approx. 850 °C.

**Suprtherm HT 175 Grade**

This medium compressed thermal insulation material with a temperature resistance up to 1000 °C is based on high-grade magnesium silicates, inorganic fibres and binders.

*Photos: Forging presses*
Electrical heaters

...Solving Heating Problems All Over The World

1045 Harts Lake Rd
Battle Creek, MI 49016
Tel (800) 937-4681 Fax (616)964-4526

Cartridge Heaters

High-Watt Density Cartridge Heaters

Hotset offers the following types of Cartridge Heaters:

- HI High Watt Density Cartridge Heater
- HI or HK High Watt Density Cartridge Heater with Thermocouple
- HI 4mm High Watt Density Cartridge Heater
- High Watt Density Cartridge Heater with integral cutting blade
- LI Medium Watt Density Highly Compressed Cartridge Heater
- NP Low Watt Density Cartridge Heater

Information Request Form - Contact Information

Send mail to webmaster@hotset.com with questions or comments about this web site.
# Electrical Heaters

**HI - High Watt Density Cartridge Heaters without TC**

![Diagram of HI Cartridge Heaters](image)

**Dimensions in mm**

- Heated Zone: 75 mm ± 1 mm
- Unheated Zone: 75 mm ± 1 mm

**Diameters Available:**

<table>
<thead>
<tr>
<th>Inch</th>
<th>1/8&quot;</th>
<th>1/4&quot;</th>
<th>3/8&quot;</th>
<th>5/16&quot;</th>
<th>1/2&quot;</th>
<th>5/8&quot;</th>
<th>11/16&quot;</th>
<th>3/4&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric</td>
<td>3.17</td>
<td>6.5</td>
<td>8</td>
<td>9.5</td>
<td>10</td>
<td>12</td>
<td>12.5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Other Diameters Available - Please Consult Factory for Others*

*All HI Type Heating Elements Are Centerless Ground as Standard*
Hi-Density Cartridge Heaters

Hi-Density Cartridge Heaters (swaged) are the solution for high temperature applications.

Hi-Density Heaters provide localized heating in processes requiring close temperature control such as:

- Dies
- Molds
- Hot stamping
- Packaging equipment
- Plastic extruders
- Injection molding mach.
- Platinens
- Labeling
- Bag sealing
- Medical equipment

Hi-Density heaters are approved as components under the UL (file number E65652) and CSA (file number LR-43099-4) recognition programs.

Maximum Temperature: 1500°F (816°C).

Custom Terminated Hi-Density Cartridge Heaters From Stock

Click to view Stock Sizes and Ratings by Diameter

1/4"  5/16"  3/8"  1/2"  5/8"  3/4"
The shot sleeve design
The shot sleeve design
The shot sleeve design
The die design
The die design
The die design