Aluminum wheel

Conventional

The distribution of heat is difficult to control to fill die cavity

Forging

Cross sectional area

Resistance Heating

Electricity

The distribution of heat is easy to control to fill die cavity

Forging

Bassim Ahmed Julaih, Materials Forming Laboratory
Contents

- Control of temperature distribution by different upper and lower heating resources
- Finite element simulation of temperature distribution in resistance heating
- Experimental Procedure of Semi-Solid Forging
- Control of Die Cavity Filling for Complex Shape
Control of temperature distribution by different upper and lower heating resources

A357 billet

Symmetrical temperature distribution
High pressure

Unsymmetrical temperature distribution
Low pressure

By using same disc thicknesses

By using different disc thicknesses
Contents

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Finite element simulation of temperature distribution in resistance heating

Temperature analysis
Joule heat + heat conduction
FEM code ANSYS

Output impedance:
0.5mΩ
### Material properties used for FEM simulation

#### Assumptions:
- No plastic deformation
- Extension of liquid phase properties from solid phase ones with linear function of temperature
- No density variation
- Variation of real contact area ratio with temperature and pressure

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density /Mg·m⁻³</th>
<th>Thermal conductivity /W·m⁻¹·K⁻¹</th>
<th>Specific heat /J·kg⁻¹·K⁻¹</th>
<th>Electrical Resistance /n Ω·m</th>
<th>Latent heat kJ·kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>A357</td>
<td>2.68</td>
<td>151.6-0.0314T</td>
<td>950.8+0.61T</td>
<td>43+0.0118T</td>
<td>389</td>
</tr>
<tr>
<td>SUS304</td>
<td>7.92</td>
<td>15+0.0143T</td>
<td>487+0.0223T</td>
<td>715+0.0583T</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>8.93</td>
<td>407.7-0.0714T</td>
<td>368.3+0.143T</td>
<td>14+0.0068T</td>
<td></td>
</tr>
<tr>
<td>Dummy</td>
<td>8.93</td>
<td>1.00E-10</td>
<td>1.00E+10</td>
<td>15700</td>
<td></td>
</tr>
</tbody>
</table>

[T/°C]
Temperature distribution in resistance heating

$t_u = 0.5 \text{mm}$

0.5mm
Temperature distribution in resistance heating

\[ t_u = 0.7\text{mm} \]

(a) \( T = 0.1\text{s} \) (b) \( T = 2\text{s} \) (c) \( T = 2.5\text{s} \) (d) \( T = 2.88\text{s} \)
Effect of SUS304 disc thicknesses on temperature distribution in central line

![Graph showing temperature distribution in central line with different disc thicknesses.](image)

- **Liquid phase**
  - Central height $h$ in mm:
    - $0.5$, $0.7$, $0.8$
  - Temperatures $T$ in °C:
    - $2.79$, $2.88$, $2.9$

- **Solid phase**
  - Central height $h$ in mm:
    - $0.5$
  - Temperature $T$ in °C:
    - $565$

The graph illustrates the temperature distribution in the central line with varying disc thicknesses, showing the transition between solid and liquid phases.
Liquid phase ratio, LPR, for A357 aluminum alloy

LPR = \frac{-4.75 + 0.0174T}{69.06 - 0.1028T}

Temperature / °C

Liquid phase ratio, LPR / %

500 550 600 650

100 90 80 70 60 50 40 30 20 10 0

46

565

614

650
Distribution of liquid phase ratio in resistance heating

(a) $t_u = 0.5\text{mm}$, $T = 2.79\text{s}$

(b) $t_u = 0.7\text{mm}$, $T = 2.88\text{s}$
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Experimental procedure of semi-solid forging

- Punch (Cu)
- Disc, tu (SUS304)
- Billet (A357) φ12 x 24h
- Punch (Cu)
- Container (SUS304)
- Disc, 0.5mm (SUS304)
- Insulation
- Anvil
- Feed line
- Pressure
Experiment conditions for resistance heating

Contact pressure, \( P_h = 10 \text{ MPa} \)

Voltage, \( E = 6 \text{ V} \)

Energy, \( Q = 25 \text{ kJ} \)

Forging pressure, \( P_f = 22, 43, 65 \text{ MPa} \)

\( t_u = 0.5, 0.7, 0.8 \text{ mm} \)

\( t = 0.5 \text{ mm} \)

\( \phi_24, \phi_16, \phi_12 \)
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Effects of SUS304 disc thicknesses and forging pressure on filling of die cavity

Complete filling

Incomplete filling

Filling ratio / %

Upper disc thickness, $t_u$ / mm

Filling ratio / %

No spark

Spark

$P_f$ / MPa

- $\circ 22$
- $\triangle 65$
- $\square 43$

Complete filling

Complete filling

Incomplete filling

Incomplete filling
Microstructure of semi-solid forging

Before heating

Q=25kJ, $t_u=0.5\text{mm}$, $P_f=65\text{MPa}$, $P_h=10\text{MPa}$

Q=25kJ, $t_u=0.7\text{mm}$, $P_f=43\text{MPa}$, $P_h=10\text{MPa}$
Hardness distribution of semi-solid forging

![Graph of Vickers hardness distribution](image)

- **Vickers hardness / HV$_{0.2}$**
- **Distance from center r / mm**
- **Original**

<table>
<thead>
<tr>
<th>$P_f$/MPa</th>
<th>65</th>
<th>43</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_u$/mm</td>
<td>0.5</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Eutectic phase distribution of semi-solid forging

![Graph showing area ratio of eutectic phase vs. distance from center r (mm).]

- **Area ratio of eutectic phase / %**
  - 60
  - 50
  - 40
  - 30
  - 20
  - 10
  - 0

- **Distance from center r (mm)**
  - 0
  - 4
  - 8
  - 12

- **Original**

- **Legend**
  - Solid line: \( P_f / \text{MPa} = 65 \)
  - Dashed line: \( P_f / \text{MPa} = 43 \)

- **Table**

<table>
<thead>
<tr>
<th></th>
<th>( P_f / \text{MPa} )</th>
<th>( t_u / \text{mm} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>65</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Conclusions

- The control of the temperature distribution using the upper and lower discs having different thicknesses in the semi-solid forging process is effective in shaping the complex shapes of parts.

- The liquid phase ratio is increased by using thick SUS304 disc.

- The forging pressure is greatly reduced with the heating for different disc thicknesses.

- The total heat generation inside the billet is equal in both of the symmetrical and unsymmetrical heating. When the temperature in the upper part of the billet is increased, it is decreased in the lower part.