Internal Void Closure During the Forging of Large Cast Ingots Using a Simulation Approach

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Location of CSM
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Co-Authors of Study

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S.U. Lee – Supervisor at POSCO Specialty Steel

B.D. Joo – Graduate Student at Pusan National University

Y.H. Moon – Professor at Pusan National University
Location of Pusan National University
Determine conditions where internal voids will close during the forging of cast ingots.

Focus is on the cogging operation.
1990 – Kiefer and Shah used 3D FEM to examine cogging. They obtained stresses and strains within the ingot.

Others also did FEM work and work continues.

1990 – Dudra and Im did 2D FEM to study closure of centerline pores. They indicated effective strain was a better measure than hydrostatic stress to indicate closure.
Previous Studies

1997 – Park and Yang used 3D FEM and found that die width ratio and die shape are beneficial for void closure.

2002 – Kim et al. used neural network for closure of voids in rectangular workpieces.

2004 – Overstam and Jarl used 3D FEM for rectangular workpieces. They found that the bite ratio was a critical factor for pore closure.
Previous Studies

2005 – Banaszek et al. used 2D FEM. Found die shape has major effect on void closure. They suggested using shaped dies during initial cogging then flat dies during later stages.

2006 – Chun et al. used 3D FEM to look at centerline voids in rectangular workpieces. They studied die width ratio, die feed rate, die shape and number of passes.

2008 – Skubisz et al. found that a critical amount of effective strain was needed to close voids.
2005 – Banaszek et al. used 2D FEM. Found die shape has major effect on void closure. They suggest using shaped dies during initial cogging.

2006 – Chun et al. used 3D FEM to look at centerline voids in rectangular workpieces. They studied die width ratio, die feed rate, die shape and number of passes.

2008 – Skubisz et al. and Lee et al. found that a critical amount of effective strain was needed to close voids.
2009 – Zhang et al. suggest that void closure depends on the hydrostatic stress.

2010 – Kakimotoa et al. created a void closing index which needed to reach a critical value. The index is very academic and complex.
Questions from Previous Work

• Is hydrostatic stress or is strain the best measure to use for void closure?

• If hydrostatic stress, what is the critical value? How should it be determined?

• If strain, what is the critical value? How should it be determined?
What is the critical amount of strain (i.e. criteria) needed for void closure?

Propose the criterion for closing voids
Experimental Approach

1. **Cast Ingot**
2. **Machining**
3. **Round bar**
4. **3D X-ray scanner** *(CT: Vendo H-450CT)*
5. **1st upsetting**

Original voids: \( (v_1, v_2, \ldots, v_n) \)

Deformed voids: \( (u_1, u_2, \ldots, u_n) \)
Round Bar with Voids

(Δ: distance from the bottom)

**Detail voids shape**

- ‘P6’
- ‘P1’
- ‘P2’
- ‘P3’
- ‘P4’
- ‘P5’

Δ: distance from the bottom

200 (top)

0 (bottom)
After First Upset

Round Ingot → Final Stage

Experiment

FEM

(Plane view) → (Section view)
After First and Second Upset

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>1\textsuperscript{st} upsetting</th>
<th>2\textsuperscript{nd} upsetting</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
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<td><img src="image5.png" alt="Image" /></td>
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<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
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</tbody>
</table>
FEM Model – First Upset

Damage

Effective strain

Temperature

Damage

Effective strain

Temperature

Experiment: 270 ton
FE-analysis: 290 ton
Three void conditions were observed:

<table>
<thead>
<tr>
<th>Case</th>
<th>First Upset</th>
<th>Second Upset</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Void closed</td>
<td>Void closed</td>
</tr>
<tr>
<td>2</td>
<td>Void closed</td>
<td>Void opened</td>
</tr>
<tr>
<td>3</td>
<td>Void open</td>
<td>Void open</td>
</tr>
</tbody>
</table>
Local effective strain of 0.6 is needed.
## Results

<table>
<thead>
<tr>
<th>Case</th>
<th>Effective Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - P2</td>
<td>0.66</td>
</tr>
<tr>
<td>2 - P3</td>
<td>0.48</td>
</tr>
<tr>
<td>3 - P6</td>
<td>0.31</td>
</tr>
</tbody>
</table>
1. Both experimental tests and FEM tests were used to examine void closure.

2. Local strain is the better measure of void closure as compared to hydrostatic stress.

3. A local critical effective strain in the region of the void of 0.6 provides enough strain for closure.

4. FEM can be used to determine local critical effective strain without having a void present.