Die Steel Improvements for AHSS Applications

Thomas Bell
HITACHI METALS LTD
Arlington Hts, IL
AGENDA

- HITACHI Intro
- Steel Production Methods for Die & Tooling Steels
- Typical Failure modes of Die Steels for AHSS
- Solutions to improve Tooling Performances
  - Steel Types, Coatings
- Hot Stamping Die Steels
- Pre Hardened Die Steels
- Grain Oriented Die Steel Study
US consolidated employees: 8,012 people (Including Japanese expats 40 people)

Number of Offices: 4 Sales offices, 19 Factories
Hitachi Tool Steel Manufacturing Process

Ask Your Tool Steel supplier……

- **Test Certifications (actuals from Mill Source)**
- **Method of Manufacturing**
  - Forged, Rolled, etc.
- **Recommended Heat Treat**
Advanced grade die materials are needed for forming AHSS. “Die Standards” have not kept up with increased strength trend.
3 Common Failure Modes

◆ 1) Chipping: Toughness is required for trims, flanges, pierce & punches

- Mechanism:
  ① Burr occurs
  ② Increase Friction
  ③ Tensile Stress
  ④ Cracking
  ⑤ Chipping

◆ 2) Galling: Galling resistance

- Mechanism:
  ① Heated up by friction
  ② Alloying (Adhesion)
  ③ Fall Away

Galling tends to occur at heavy loaded area
3) Wear:

- Surface Coating advancements have greatly improved steel performances

- Hard Particle (Oxide, hardened steel, etc..)
Questions about Stamping Die Application

- Part material
  - Aluminum or Steel: What type & thickness?
- Press Size (Servo or Mechanical) & Strokes per minute cycle
- Current Die Construction
  - Progressive or Transfer?
  - Castings? Inserts?
  - Tooling steels used?
    - What coating?
- Die Clearance
- Heat Treating Recipe
- Welding (In House? Outsource? Consumable used?)
- Failure Observations: What Happened?
- What's been tried so far?

Solution & Engineering Center
Matsue, Japan
## Standard Grades for Tooling

<table>
<thead>
<tr>
<th>Grade</th>
<th>AISI</th>
<th>JIS</th>
<th>DIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>SKD12</td>
<td>SKD12</td>
<td>DIN 1.2601</td>
</tr>
<tr>
<td>M2</td>
<td>SKH51</td>
<td>SKH51</td>
<td>DIN 1.3343</td>
</tr>
<tr>
<td>H13</td>
<td>SKD61</td>
<td>SKD61</td>
<td>DIN 1.2344</td>
</tr>
<tr>
<td>S7</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>D2</td>
<td>SKD11</td>
<td>SKD11</td>
<td>DIN 1.2379</td>
</tr>
<tr>
<td>D2</td>
<td>SKD11</td>
<td>SKD11</td>
<td>DIN 1.2379</td>
</tr>
<tr>
<td>8% Cr</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>MATRIX : YXR33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8% Cr</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Tool Steel Alloy Design

Other Factors
1) Commercial Availability
2) Cost
3) Weldability
4) Coat-Ability

3 to 4% V PM

8%Cr steel

SLD Magic™

YXR MATRIX

SLD-i™

10% V PM

CARBIDE

Our Heritage, Your Advantage
Yasugi Specialty Steel
Microstructure

Coarse & directional carbide
- Large & anisotropic deformation after heat treatment
- Medium galling & wear resistance
- Characteristics will be affected by grain direction

Small, dense & homogeneous carbide
- Small & isotropic deformation after heat treatment
- Same HT & Chem as D2
- Good galling & wear resistance
- Achieve higher hardness than D2/1.2379
Bending test

**Conditions**

- Bead
- Load
- Punch
- Die

**Initiation point and direction of galling**

**Dies**

- Polished by #8000 paper (2-4μm)
- Hardness: 60HRC

**Work piece:**
- HSS
- 980MPa
- 1.4mm Thick

**Schematic diagram of test condition**

**Work piece after test**
A abrasive Wear Test

**Conditions**

Pin-on-disc method (ASTM G99-05)

<table>
<thead>
<tr>
<th>Item</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test piece</td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td>D2, SLD-i, and 8Cr</td>
</tr>
<tr>
<td>Hardness</td>
<td>60, 62HRC</td>
</tr>
<tr>
<td>Disc</td>
<td>Alumina</td>
</tr>
<tr>
<td>Surface pressure</td>
<td>7.8 MPa</td>
</tr>
<tr>
<td>Friction Speed</td>
<td>0.42 m/s</td>
</tr>
<tr>
<td>Friction length</td>
<td>377 m</td>
</tr>
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</table>

**Results**

<table>
<thead>
<tr>
<th>Specific wear rate ($\times 10^{14}$, m$^2$/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60HRC SKD11</td>
</tr>
<tr>
<td>60HRC AISI D2</td>
</tr>
<tr>
<td>60HRC SLD-i</td>
</tr>
<tr>
<td>62HRC</td>
</tr>
<tr>
<td>8%Cr$_3$</td>
</tr>
</tbody>
</table>
Impact Toughness

Notch: 10R
Direction: L-T
Thickness: > 60 mm

(Q)1030°C
(T)500-520°C
Hardness: 61-62HRC
Less wear ⇒ Die life 30%UP

Test results of SLD-MAGIC® by customers

Product: Liquid crystal panel parts
Forming: Blanking
Present: 8%Cr steel
Work material: SS 3 mm thick

<table>
<thead>
<tr>
<th>Present</th>
<th>S-MAGIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>8%Cr steel</td>
</tr>
<tr>
<td>Hardness</td>
<td>60~62HRC</td>
</tr>
<tr>
<td>Heat treatment</td>
<td>Temper 505°C</td>
</tr>
<tr>
<td>Distortion</td>
<td>0.05%</td>
</tr>
<tr>
<td>Machinability</td>
<td>Normal</td>
</tr>
<tr>
<td>Life</td>
<td>30,000 hits</td>
</tr>
<tr>
<td>Damage</td>
<td>Burr(wear out)</td>
</tr>
</tbody>
</table>

Forming: Blanking
Present: 8%Cr steel
Work material: SS 3 mm thick

- Grade: 8%Cr steel
- Hardness: 60~62HRC
- Heat treatment: Temper 505°C
- Distortion: 0.05%
- Machinability: Normal
- Life: 30,000 hits
- Damage: Burr(wear out)
Test results of SLD-MAGIC® by customers

Product: Automobile parts  
Forming: Blanking  
Present: D2  
Work material: 780MPa AHSS: 1.8 mm

<table>
<thead>
<tr>
<th></th>
<th>Present</th>
<th>SLD-MAGIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>D2</td>
<td>58~60HRC</td>
</tr>
<tr>
<td>Hardness</td>
<td>58~60HRC</td>
<td>Temper 170°C</td>
</tr>
<tr>
<td>Heat treatment</td>
<td>Temper 170°C</td>
<td>&gt;40,000 shots</td>
</tr>
<tr>
<td>Life</td>
<td>6,000~15,000 shots</td>
<td>large crack</td>
</tr>
</tbody>
</table>

(SLD-MAGIC) Small crack  
⇒ Possible to repair by welding  
⇒ Die life is longer

※ repaired by welding at 25,000 hits
Heat Treatment Deformation Minimization
Distortion on SLDi vs D2
Example Part material 2.5 mm thick Aluminum

Before test:
- D2 had to be re-conditioned @ 80,000 strikes due to galling
- Re-Polish, re-coated

Start SLDi (HITACHI D2)
Test SLD-i material (Hitachi Metal) Full Harden 62HRC only
- Maintain steel polish 1/ month (Ave. 65,000 hit)
- Maintenance time reduced to 83% from original condition

- SLDi steel is better result than D2+Coating
Concept of Pre-Hardened Die Steels

D2

Annealed → Machining → Heat Treat → Hardened 60HRC → Finishing → Coating TD/CVD → ~510°C → Adjust Rework → Mass-Production

Customer’s Process

SLD-F NEW STEEL

Hardened → Machining Finishing → Trial use → Rework → Coating PVD → ~510°C → Mass-Production

Customer’s process
Machining of Pre-Hard Tool Steels @ 60 HRC

1) Machine Tool
   - Rigid Construction:
     • High Spindle Speed: 20,000+

2) Cutting Tool
   • Solid Carbide with ductile properties for interrupted cut

3) Consistent substrate of Die Steel
## Effect on Machinability

### Table. Chemical composition (mass%)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Al</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLD F</td>
<td>Lower than D2</td>
<td>Higher than D2</td>
<td>Higher than D2</td>
<td>Trace</td>
<td>Lower than D2</td>
<td>Higher than D2</td>
<td>Trace</td>
<td>Trace</td>
<td>-</td>
</tr>
<tr>
<td>D2</td>
<td>1.55</td>
<td>0.3</td>
<td>0.4</td>
<td>-</td>
<td>11.8</td>
<td>0.8</td>
<td>0.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8Cr(A)</td>
<td>0.9</td>
<td>0.9</td>
<td>0.5</td>
<td>-</td>
<td>7.8</td>
<td>2.5</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8Cr(B)</td>
<td>1.1</td>
<td>0.9</td>
<td>0.4</td>
<td>-</td>
<td>8.3</td>
<td>2.1</td>
<td>0.5</td>
<td>Trace</td>
<td>Trace</td>
</tr>
</tbody>
</table>

### Decreasing carbides

- SLD- F has good machinability even @ 60HRC due to less primary/secondary carbide.

### Belag formation

- In order to prevent the wear and improve the life of die, PVD coating on the surface of the dies is recommended.

A sample microstructure of SLD-F
Mechanism of better machinability

Cause of tool wear and chipping
- Adhesion of die steel
- Cutting resistance by carbides

- Being less the carbide contribute to being less cutting resistance.
- Oxide layer formation called “Belag” on the surface of the cutting tool during cutting plays prevent the cutting tool from chipping.
# Simulation: Process cost and lead time of Pre-Hard

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>Time</th>
<th>Time</th>
<th>Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Steel</td>
<td></td>
<td></td>
<td>$600</td>
<td>$1,105</td>
</tr>
<tr>
<td>Drilling</td>
<td>.5 Hr.</td>
<td>3.5 Hrs.</td>
<td>$240</td>
<td>$1,440</td>
</tr>
<tr>
<td>Milling</td>
<td>10 Hrs.</td>
<td>16 Hrs.</td>
<td>$4,160</td>
<td>$6,260</td>
</tr>
<tr>
<td>HT Prep</td>
<td>2 Hrs.</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HT</td>
<td>72 Hrs.</td>
<td></td>
<td>$290</td>
<td>0</td>
</tr>
<tr>
<td>Fin Mach.</td>
<td>12 Hrs.</td>
<td>12 Hrs.</td>
<td>$2,000</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>96 Hrs.</td>
<td>31 Hrs.</td>
<td>$7,535</td>
<td>$8,805</td>
</tr>
</tbody>
</table>

**Condition of simulation**

Material weight: 160 lbs.

M16 hole x 5 locations
M16x25H tapped hole x 2 locations
Lead Time comparison: DieMaker (Automotive) in Japan

Improvement (Decrease in lead time)

- Drilling
- Rough machining
- Surface grinding
- Polishing for shape correction
- Finish machining
- Wire cutting

Total process time for die-making

Die size: 390x150x130 mm (50kg)
HOT STAMPING  1200 MPA +

• Demands on Die Materials
  – Wear
  – Conductivity
  – Watch for industry developments on 3D Additive Mfg. inserts w/ conformal cooling lines

• Use of higher alloyed Die Steel
## Hot Work Die Steels: NADCA Rated

### Cross Reference Guide to Special Quality Die Steels

<table>
<thead>
<tr>
<th>NADCA Grade</th>
<th>Trade Name</th>
<th>Type</th>
<th>Preheating Temp, °F(°C)</th>
<th>Austenitizing/Hardening Temp. °F(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Type H13- Premium*</td>
<td>A1885</td>
<td>1100-1250 (595-675)</td>
<td>1500-1560 (815-850)</td>
</tr>
<tr>
<td>B</td>
<td>Type H13-Superior</td>
<td>B1885</td>
<td>1100-1250 (595-675)</td>
<td>1500-1560 (815-850)</td>
</tr>
<tr>
<td>C</td>
<td>Type 2367 &amp; Modified</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uddeholm Dievar</td>
<td>C1850</td>
<td>1100-1200 (595-650)</td>
<td>1500-1560 (815-850)</td>
</tr>
<tr>
<td></td>
<td>Hitachi DAC MAGIC</td>
<td>C1870</td>
<td>930-1290 (500-700)</td>
<td>1380-1470 (750-800)</td>
</tr>
<tr>
<td></td>
<td>Böhler W403 VMR</td>
<td>C1885</td>
<td>930-1020 (500-550)</td>
<td>1375-1475 (745-800)</td>
</tr>
<tr>
<td></td>
<td>Ellwood ExEll Hot Die</td>
<td>C1885</td>
<td>1100-1200 (595-650)</td>
<td>1475-1525 (800-830)</td>
</tr>
<tr>
<td></td>
<td>Kind RPU</td>
<td>C1885</td>
<td>1100-1200 (595-650)</td>
<td>1500-1560 (815-850)</td>
</tr>
<tr>
<td></td>
<td>Schmolz+Bickenbach Thermodur 2367</td>
<td>C1885</td>
<td>1100-1200 (595-650)</td>
<td>1500-1560 (815-850)</td>
</tr>
<tr>
<td></td>
<td>Daido DH31-EX</td>
<td>C1885</td>
<td>1020-1200 (565-650)</td>
<td>1470-1560 (800-850)</td>
</tr>
</tbody>
</table>
HOT STAMPING DIE MATERIALS

• Upgrade to a NADCA Class C Hot Work Steel in place of AISI H13

1. Conductivity
   - Class B H13 is 32.6 @ 600C
   - Class C is 35.8 @ 600C
   - Better for heat conductivity than H13 means better cycle times.

2. Toughness:
   - Why? Higher Impact Values (charpy) prevent cracking on the surface of Hot Stamping Dies close to the cooling channel.

3. Wear:
   - Why? NADCA Class C (HITACHI DAC-MAGIC) is higher strength under high temperature. Die surfaces can reach ~ 400C & higher alloyed steels are needed to extend wear.

4. Coatablity
   - Coatable and Wear resistance at room temperature, almost same as H13.
Yield, Tensile Strength and Impact Strength

<table>
<thead>
<tr>
<th></th>
<th>Room temperature</th>
<th>650°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield strength</td>
<td>Tensile strength</td>
</tr>
<tr>
<td>DAC-Magic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NADCA Class C</td>
<td>1238</td>
<td>1479</td>
</tr>
<tr>
<td>NADCA Class B</td>
<td>1211</td>
<td>1444</td>
</tr>
<tr>
<td>(H13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4% Better</td>
<td>2.5% Better</td>
<td>5% Better</td>
</tr>
</tbody>
</table>

Charpy Impact (ft.-lbs.)

- **Grade C**
  - Average value: DAC-Magic
  - Minimum value: H13
- **Grade B**
  - Average value: DAC-Magic
  - Minimum value: H13

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## Case studies

<table>
<thead>
<tr>
<th>Applications</th>
<th>Formed Article</th>
<th>Die</th>
<th>Work piece</th>
<th>Die material</th>
<th>Conventional Coating</th>
<th>Comparison (Die life)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold stamping</td>
<td>Lower arm</td>
<td>Bending</td>
<td>590 MPa HSS (3.6mm)</td>
<td>SLD-MAGIC*</td>
<td>TiCr</td>
<td>× 8.1</td>
</tr>
<tr>
<td>Cold stamping</td>
<td>Exhaust part</td>
<td>Throttling</td>
<td>Stainless steel (1.4mm)</td>
<td>Cold Work tool steel</td>
<td>+Nitriding</td>
<td>× 7.5</td>
</tr>
<tr>
<td>Cold stamping</td>
<td>Exhaust part</td>
<td>Mandrel</td>
<td>Stainless steel</td>
<td>YXR7</td>
<td>TiCN +Nitriding</td>
<td>× 5</td>
</tr>
<tr>
<td>Cold stamping</td>
<td>Driving part</td>
<td>Burring punch</td>
<td>—</td>
<td>SLD-MAGIC*</td>
<td>VC</td>
<td>× 4</td>
</tr>
<tr>
<td>Cold stamping</td>
<td>Clutch part</td>
<td>Burring punch</td>
<td>—</td>
<td>SLD*</td>
<td>VC</td>
<td>× 7</td>
</tr>
<tr>
<td>Hot Stamping</td>
<td>Pillar</td>
<td>Bending</td>
<td>1470 MPa (1.4mm)</td>
<td>Hot Work tool steel</td>
<td>AlCr</td>
<td>× 3</td>
</tr>
<tr>
<td>Hot Stamping</td>
<td>Pillar</td>
<td>Bending</td>
<td>1470 MPa (1.4mm)</td>
<td>Hot Work tool steel</td>
<td>Nitride+V</td>
<td>× 2</td>
</tr>
</tbody>
</table>

CrWN
DOES GRAIN DIRECTION ON DIE INSERTS MATTER?

• What is anticipated highest Impact Area?
• Is Grain direction detectable?
  • Can this detail be marked?
EXAMPLES of GRAIN

Rolling or Forging Direction
Orientation Diagram
Arrows indicate the direction of the impact force

CONCLUSION: **Grain Matters**
Impact Toughness Tests: Short-Transverse

<table>
<thead>
<tr>
<th>Material</th>
<th>Ft Lbs</th>
<th>HRC Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>NADCA Class C Mod HW DAC Magic</td>
<td>17.3</td>
<td>48</td>
</tr>
<tr>
<td>NADCA Class B Prem H13 DAC P</td>
<td>19</td>
<td>48</td>
</tr>
<tr>
<td>8% Cr SLD Magic</td>
<td>2.66</td>
<td>58</td>
</tr>
<tr>
<td>D2</td>
<td>1.6</td>
<td>59</td>
</tr>
<tr>
<td>M2</td>
<td>2</td>
<td>64</td>
</tr>
<tr>
<td>SLDi</td>
<td>1.6</td>
<td>59</td>
</tr>
</tbody>
</table>
Conclusions

• Review Die Standards & allow for areas requiring better tooling steels in trouble-spots
• Compare results with other steels in side by side like-environments
• Insist on controlled HT path & Welding steps
• Ask for grain orientation on larger cross sections
• “If you can’t use a better tool steel, use your tool steel better”
THANK YOU

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For More Information

- Sources for More Info
  - Exova Element Lab
  - Mitsubishi – Hitachi Tool
  - Ceratizit Carbide & HB Carbide
  - BayCast
  - AutoSteel Partnership: Great Designs in Steel
  - TCI Coatings in Olivet, MI
  - Schuler