Optimization of stamping tools to process very high strength steels; comparison of cold work tool steels

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Outline

• Background
  – Tool Wear Mechanisms - Failure Modes
• Tool Steel Formulation
  – Properties
• Experimental Work
  – Experimental Set up
  – Experimental Results
• Industrial Applications/Examples
• Conclusions
Cutting/Trimming process

**Displacement**

- Friction
- Tool surface properties

**Stresses**
- Core properties
- Plastic (permanent) deformation

**Abrasive wear** (hard material)

**Adhesive wear** (soft material)

**Additional phenomenon**

**Impact**

Shock wave due to brittle fracture of processed material (UHSS)

Chipping
- Microchipping
- Cracking

**Adhesive wear** (soft material)
Forming/Trimming Process

Displacement

Friction Tool surface properties

Stresses Tool core properties

Abrasive wear (hard material)

Adhesive wear (soft material)

Surface fatigue
Cracking/Chipping
Plastic deformation

+ Peeling of coating
Challenges for Tool Steels for processing VHSS/UHSS

**Cutting/Trimming**

1. Microchipping → Chipping → cracking
2. Plastic deformation
3. Abrasive wear

Choose tough substrate

**Forming**

1. Abrasive wear
2. Surface fatigue / chipping

Select appropriate substrate/coating
Substrate properties for processing VHSS/UHSS

- Toughness (Charpy)
- Compressive strength (Yield Strength)
- Compatibility with surface treatments of coating
- Repairability (welding)
- Hardness (Surface)
- Machinability
- Heat treatment

Properties addressed in the formulation of TENASTEEL®
## Characteristics/Properties of Tool steels

### Tool materials characteristics:

<table>
<thead>
<tr>
<th>Product name</th>
<th>Type</th>
<th>Euronorm</th>
<th>Hardness</th>
<th>Compressive strength (MPa)</th>
<th>Toughness* (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z160CDV12 (D2)</td>
<td>Cold work high chromium tool steel</td>
<td>X153 CrMoV12 (W.Nr.: 1.2379)</td>
<td>As Delivered: 250 HB max</td>
<td>58 / 62 HRC</td>
<td>2200</td>
</tr>
<tr>
<td>Tenasteel</td>
<td>Cold work tool steel</td>
<td>X110 CrMoV8 family</td>
<td>Hardened condition: 250 HB max</td>
<td>58 / 62 HRC</td>
<td>2510</td>
</tr>
</tbody>
</table>

* Unnotched specimen

### Chemical analysis

<table>
<thead>
<tr>
<th>Product name</th>
<th>Chemical analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z160CDV12 (D2)</td>
<td>C 1.55  Si 0.30  Mn 0.35  Cr 11.75  Mo 0.75  V 0.75</td>
</tr>
<tr>
<td>Tenasteel</td>
<td>C 1.0  Si 0.35  Mn 7.5  Cr 2.6  Mo 0.3</td>
</tr>
</tbody>
</table>

- Large chromium carbides
- Fine carbides of Chromium/Molybdenum/Vanadium
- Titanium precipitates
Compression strength is necessary to avoid permanent deformation in high stressed area when processing VHSS/UHSS

- Minimum 58 HRC necessary
- TENASTEEL provides better resistance than D2

**Powder Metal (PM) Grades**
- Most provide very high wear resistance
- Toughness not correspondingly high

*Unnotched specimen*
Experimental Work
AIM:
- Provide guidelines to customers in terms of
  - tool material and coating,
  - Process parameters (cutting clearance)

PROCEDURE:
- In line cutting (total: 500,000 strokes per configuration)
- Observations and measures during the campaign:
  - Detailed Examination of tools (observations, profiles, SEM analysis)
  - Detailed examination of parts (cut-edge quality (cf. Punching test), hole expansion test)
  - Data acquisition (force-displacement curves)
Experimental Set-up

- **Steel sheet:** DP 980, 1.6mm
- **Part geometry:** 20mm diameter disc
- **Tool configurations (tested clearances)**

<table>
<thead>
<tr>
<th>Tool material</th>
<th>Coating</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bare</td>
<td>TiN</td>
<td>AlCrN</td>
</tr>
<tr>
<td><strong>D2</strong> (Industeel)</td>
<td>7%</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td><strong>Tenasteel</strong> (Industeel)</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product name</th>
<th>Requirement (HRC)</th>
<th>Hardness (HRC) (measured on tools)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D2)</td>
<td>58/60</td>
<td>58</td>
</tr>
<tr>
<td>Tenasteel</td>
<td>58/60</td>
<td>59/60</td>
</tr>
</tbody>
</table>

Shape of cutting edge

Punch Body

The edge

The face

Blanking
Investigation methodology for each tool configuration

- Punch damage analysis through
  - 3D profile measurement
  - Bino and SEM observations

- Influence of punch damage on sheet product
  - Cut-edge shape
  - Burr height
  - Stroke height through force/displacement curve
  - Cut-edge formability through hole expansion test

- Frequency
  Each configuration is totally characterized:
  - After 1, 30, 100, 500, 1000, 2500 strokes
  - From 5000 to 20000 strokes by 5000 steps
  - From 20000 to 100000 strokes by 20000 steps
  - From 100000 to 500000 strokes by 40000 steps
Experimental Results
Definition of tool wear mechanisms

Substrate degradation

- **Adhesion / sticking**: Some sheet steel particles (debris) sticks on the tool

- **Abrasive wear**: Friction scratches can clearly be identified in the punching direction

**NB**: In our case, this mechanism was microscopical → not observed visually.
Definition of tool wear mechanisms

Substrate degradation

- **Cracking**: Cracks (usually circumferential) occur in the substrate.

- **Chipping / Microchipping**: A small part of material breaks away from the tool. (microscopic scale: microchipping, eye visible: chipping)

**NB**: Microscopic mechanism → Can not be observed visually.
• **Edge collapse**: (often occurs as a consequence of chipping) A large amount of the edge is destroyed – the edge shape is then no longer triangular but flattened (see graph below)
Definition of tool wear mechanisms
Coating degradation

- **Coating cracking**: Cracks (usually circular) in the coating

- **Coating flaking**: Coating delaminates from the substrate and flakes off

NB: Difficult to see visually (naked eye)
Definition of tool wear mechanisms
Effect of Worn Tool on Sheet Steel Edge

Co-relation between Cut-edge Burr and Tool wear
Experimental Results
Burr height evolution

- Significant and early increase of burr height for **D2 tools** (180 000 strokes for bare tool and even less than 100 000 strokes for coated tools) – final height is more than 10% of the sheet thickness
### Major degradation modes

#### Tools – Uncoated (Bare)

<table>
<thead>
<tr>
<th>Number of parts</th>
<th>≤5 000</th>
<th>10 000</th>
<th>20 000</th>
<th>60 000</th>
<th>100 000</th>
<th>180 000</th>
<th>300 000</th>
<th>380 000</th>
<th>420 000</th>
<th>500 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2 Bare 7%</td>
<td>sticking</td>
<td>Abrasion</td>
<td>Significant Abrasion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2 Bare 12%</td>
<td>sticking</td>
<td>Abrasion</td>
<td>Significant abrasion</td>
<td>Local chippings</td>
<td>Matter loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenasteel Bare 12%</td>
<td>sticking</td>
<td>Abrasion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Cutting clearance:
- Low cutting clearance (7%): problems at the early stages of the campaign

#### Until 180 000 strokes:
- Good resistance of both D2 and Tenasteel

#### After 180 000 strokes:
- **D2**: localized chipping leads to significant loss of matter at the cutting edge (part quality is impacted)
- **Tenasteel**: abrasive wear until 500 000 strokes, slow degradation of the tool - After 400 000 strokes, the matter loss due to abrasive wear is significant.
## Tool Wear Analysis

### Non-coated (bare), 12%-clearance

<table>
<thead>
<tr>
<th>D2</th>
<th>Hardness: 58HRC (58-60HRC required)</th>
<th>Punch diameter: 20mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roughness: 0.04</td>
<td>Punch edge radius: 10-20µm</td>
</tr>
</tbody>
</table>

### Tool evolution:
- Homogeneous abrasive wear
- Chipping observed after 180,000 strokes then significant edge collapse at 380,000 strokes (~ ¼ of the tool affected)

### Tool evolution:
- Important homogeneous abrasive wear
- No chipping ➔ good resistance of the material
Major degradation modes
TiN-coated tools

Number of parts

- ≤5 000
- 10 000
- 20 000
- 60 000
- 100 000
- 180 000
- 300 000
- 380 000
- 420 000
- 500 000

D2
- TiN
  - Coat. flaking
  - Coating cracking
  - Coating loss
  - Cracks in substrate
  - Edge collapse

Tenasteel
- TiN
  - Coating cracking
  - Loss coating
  - 200µm uncoated
  - Cracks in substrate

- No sticking phenomena and delayed abrasive wear with PVD-coating

For D2 and Tenasteel, cracks in the coating are clearly identified as the first damaging mode.

Then the coating flakes along the cracks on uncoated areas, cracks in the substrate are visible (on every punch).

Chipping always follow the cracks initiated in the substrate then matter loss at punching edge ➔ Significant degradation of parts quality.

Significant degradation on parts:
(significant and sudden increase of burr height and / or significant decrease of formability on cut-edge)
Tool Analysis – Influence of Coatings
Punch: Tenasteel, bare, 12%-clearance

Bare

TIN

AlCrN
Summary of Experimental Work

- **Forces:**
  - No significant effect of tool wear on cutting forces

- **PVD-coating:**
  - Suppresses / decreases adhesive wear,
  - TiN coating enables a longer resistance than AlCrN coating

- **Substrate influence:**
  - Tenasteel lasts significantly longer than D2 tools (with the same coating configuration)

- **Burr height evolution:**
  - Early and high increase of burr height with Z160CDV12 tools
  - Important / sudden increases of burr height often linked to local chippings / edge collapse
  - No important increase of burr height for every other configurations until 200 000 strokes

- **Formability:**
  - Formability loss is linked to any local heterogeneity on cut-edge
When cutting DP980

- Very small clearances must be avoided \(\Rightarrow\) \(\sim 12\%\) of the thickness is recommended
- Traditional Z160CDV12 (D2) bare, clearance 12\% is a good solution:
  - For small series [equivalent to less than 100,000 parts (20mm-discs)]
  - CAUTION: Ensure steel cleanliness
  - But major risk: failure/chipping
- Tenasteel (or a material from X110 CrMoV8 family) bare,
  - Clearance of 12\% material thickness Clearance is optimal configuration:
    - For longer series or for less frequent reworking (at least twice the life time of D2)
    - Major risk (Failure / chipping) decreased with the higher toughness
- PVD-coating (TiN/AlCrN) does not offer any benefit:
  - Only has an effect on adhesive and abrasive wear
  - Do not decrease the chipping/failure risk
Industrial Applications of TENASTEEL®
### Industrial Application – Seats Side member

<table>
<thead>
<tr>
<th>Component</th>
<th>Seat Side-members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet Material</td>
<td>S420 MC (YS 420 MPa, TS 550 MPa)</td>
</tr>
<tr>
<td>Thickness</td>
<td>1.5 mm</td>
</tr>
</tbody>
</table>
| Tools              | Trimming blade Tenasteel replacing D2  
                    | Hardness 58 HRC ; Bare |

**Results**
- Less re-sharpening
- Maintenance every 100 000 strokes instead of 20 000 with D2.
- Welding without preheating

*Tool Life + 500 % Improvement*
**Industrial Application – Hot Stamped B-pillar**

<table>
<thead>
<tr>
<th>Component</th>
<th>B.Pillar (1.6 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bumper beam (1.8 mm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sheet Material</th>
<th>USIBOR 1500MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>1.6 mm &amp; 1.8 mm</td>
</tr>
</tbody>
</table>

| Tools            | Trimming blades after hardening |

**Results**

- 1.6 mm → ~80 000/90 000 hits (D2 do not work at all)
- 1.8 mm → ~40 000 hits
Industrial Application – Laser welded Blank

Component: Laser Welded Blank

Sheet Material: FB 400
YS~450MPa; TS 600MPa (min)

Thickness: 3.0 mm

Tools: Cutting blade Substituted for PM tool
Hardness 58/60 HRC; Bare
Blade thickness 60 mm

Results:
- Less chipping, easier maintenance (welding)
- Re-sharpening every 150 000 strokes

Significant Cost Savings
Automotive Examples

Component: Welded blank for a front rail
Worked steel: FB600
Thickness: 3 mm
Uncoated TENASTEEL® blades (60 mm) - Hardness 58/60 HRC

- Tenasteel used in substitution to PM - less chipping problems and easier weld repairs
- More than 300000 cut blanks

Piece: Closed plate members
Worked steel: DP 600
Thickness: 1.6 mm
Uncoated cutting blade - Tenasteel used in substitution to D2 - Hardness 58 HRC
Tool life improvement: 300% (about 200000 pieces)

Piece: B Pillar; bumper beam
Worked steel: USIBOR 1500
Thickness: 1.6 mm
Uncoated trimming blade
Hardness 58 HRC

Tool life improvement: 400 to 500% (about 12000 parts)

Piece: Front bumper beam
Worked steel: DP 1180
Thickness: 1.6 mm
Uncoated trimming blade - 58 HRC Tenasteel used in substitution to D2 58 HRC

Piece: Suspension arm
Worked steel: FB600
Thickness: 4 mm
Uncoated cutting blade - Tenasteel used in substitution to D2 - Hardness 58/60 HRC
Tool life improvement: 200% with about 100000 pieces
Next Steps

Planned Activities in North America

VHSS/UHSS cutting tools

Non-Automotive

• ArcelorMittal Indiana Harbor CAL Line – Entry Shear Knives
• IN-TEK/IN-KOTE - Slitting knives for Pickling unit
• ArcelorMittal Cleveland Plant – Slitting knives for Pickle unit
• Flat Rock Processing – Scrap Chopper Knives

Automotive Trials

• Trimming tool for Hot-stamped USIBOR
• Trimming tool for DP980 CR
• Other.........

Experimental Work

• Phase II – USIBOR?
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Questions