Tribology of Hot Forming Tool and High Strength Steels

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Outline

• High temperature tribology

• Hot metal forming

• Objectives

• Results

• Conclusions
What is high temperature tribology?

Above ~300 °C liquid and semi-solid lubricants do not work

Typical applications are:

- Aerospace
- Power generation
- Metal working
High temperature tribology – a complex process

Parameters influencing tribological behaviour

- Adhesion
- Heat conduction
- Oxidation
- Diffusion
- Thermal fatigue
- Microstructural changes
- Thermal softening
Hot metal forming

• Forming metals at high temperatures has been done by blacksmiths for a long time

• Heating a steel workpiece results in:
  – Increased ductility
  – Reduced yield point
  – Easier forming

• Automated processes
  – Dimensional tolerances
  – Controlled mechanical properties
  – Productivity
Ultra high strength steels

• Automotive industry working towards:
  – Reduced weight $\rightarrow$ reduced emissions
  – Improved crash performance
  – Raw material savings

• Increased usage of ultra high strength steel (UHSS) parts

• Cold forming of UHSS
  – Springback
  – Tolerances
Hot sheet metal forming

Typical hot sheet metal forming process

Benefits:

- Easy forming of complex geometries
- Good dimensional tolerances
- Very good mechanical properties of formed part
- Tailored microstructure
Hot metal forming and tribology

- Very limited research so far

- Main tribological challenges in hot metal forming:
  - Controlled friction
  - Improved wear resistance of tools

Quality

Process economy

Wear behaviour?
Hot metal forming and tribology

Importance of friction control

Simulation of a three point tube bending operation at 800 °C
(Ø40 mm and wall thickness = 2.5 mm)

Test setup

Results from simulation
Objectives

- To experimentally characterise and understand the tribological behaviour of hot forming tool steels and ultra high strength boron steel both room and elevated temperatures

- To investigate and understand the mechanisms governing friction and wear at different temperatures

- To explore the potential of certain surface modification technologies
Tribological studies using simulative tribometer

Tool steel specimen

Untreated
$R_a = 2.75 \, \mu m$
$HV = 385$

Plasma nitrided
$R_a = 3.02 \, \mu m$
$HV = 650$

Al-Si coated
$R_a = 0.98 \, \mu m$

Ultra high strength boron steel

Nitrided + TiAlN
$R_a = 1.88 \, \mu m$
$HV = 2977$

Al-Si + graphite coated
$R_a = 1.81 \, \mu m$

Uncoated
$R_a = 0.27 \, \mu m$
$HV = 311$
Tribological studies using simulative tribometer
Tribological studies using simulative tribometer

Run-in tools

Uncoated UHSS

Al-Si coated UHSS

Al-Si + graphite coated UHSS

Coefficient of friction

Sliding distance [mm]
Tribological studies using simulative tribometer

- Adhesive and abrasive wear
- Transfer of Al-Si coating to the tool steel surface
- Less adhesive wear compared to untreated tool steel
- Transfer of Al-Si coating to the tool steel
- Reduced severity of adhesion and abrasion
- Some transfer of Al-Si coating to the tool steel surface
Conclusions

• The operating temperature has been shown to influence the friction and wear behaviour of tool steel and UHSS tribo-pairs.

• Generally, friction is reduced at elevated temperatures while wear increases with temperature.

• The most significant contributing wear mechanisms are adhesive and abrasive wear.

• Plasma nitriding of the tool steel is effective in reducing friction and wear at elevated temperatures and provides protection against severe adhesive wear (i.e. galling).
Conclusions

• Use of a surface coating on tool steel increases its wear resistance at elevated temperatures but led to high and unstable friction in the case of TiAlN coating.

• Application of a coating on the UHSS has a more pronounced effect on the friction behaviour compared to surface modification of the tool steel.

• MoS$_2$-Ti coating has good potential at moderate temperatures but its tribological performance deteriorates at elevated temperatures.
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Thank you for your attention!