Hardened Steel Turned with a Rotary Cutting Tool

Vincent Dessoly
Jeff Smith
Sathyan Subbiah
Dr. Shreyes Melkote
Hard Turning Challenges

1. Heat Generation
   • Accelerated Tool Wear
   • Thermal Softening

2. White layer formation near surface

Solution

1. Rotary cutting tools
   • Self-Propelled
   • Driven
Research Objectives

Assess Performance of Rotary Tools for Hard Turning

1. Surface Integrity Issues - specifically white layer formation

2. Model Temperature Distribution
   • Develop Finite Element Method (FEM) Model
   • Validate Model
     ▪ Measure Temperature Distribution w/ IR Thermal Camera
     ▪ Compare Rotary & Fixed Cutting Tools

3. Compare Tool Wear for Different Tool Materials
FEM Model Assumptions

1. Cutting Edge is always SHARP

2. All energy involved in plastic deformation is converted into heat

3. Primary & secondary deformation zones are plane surfaces

4. Heat generated along friction interface is evenly distributed
**Model Basis**

**Energy Partitioning Diagram**

\[
\begin{align*}
\text{Chip} & \quad \text{Cutting tool} \\
(1 - R_1)Q_1 & \quad R_1Q_1 \\
(1 - R_2)Q_2 & \quad R_2Q_2 \\
(1 - R_3)Q_3 & \quad R_3Q_3
\end{align*}
\]

**Temperature**

\[
\rho_i c_i \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = \rho_i c_r \omega_r \left( -y \frac{\partial T}{\partial x} + x \frac{\partial T}{\partial y} \right)
\]

**Heat Flux**

\[
q_f = \frac{P_f}{A_{ct}} \\
q_f = \frac{FV_{cr}}{A_{ct}} \\
q_f = \frac{2FV_{cr}}{ml}
\]

**R_2** = Heat partitioning coefficient
- related to tool & chip conductivity
Model Results

Fixed Tool

Rotary Tool

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Experimental Work

Rotary Technology Tool Holder

Cutting Insert

Rotary Cartridge

Fixed Cartridge
Experimental Work

Setup for temperature measurements

Self-Propelled Rotary Tool (SPRT) process

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FT vs. SPRT Temp. Distribution

Measured FT Temperature
\[ V_w = 10 \text{ m/min} \]
\[ f = 0.1 \text{ mm/rev} \]
\[ \text{DOC} = 0.05 \text{ mm} \]

Measured SPRT Temperature
\[ V_w = 10 \text{ m/min} \]
\[ f = 0.1 \text{ mm/rev} \]
\[ \text{DOC} = 0.05 \text{ mm} \]
Model vs. Experimental

SPRT Predicted vs. Measured

FT vs. SPRT
# Microstructure Results

<table>
<thead>
<tr>
<th>Cutting Velocity (m/min)</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td><img src="image" alt="White layer (WL)" /></td>
<td><img src="image" alt="White layer" /></td>
<td><img src="image" alt="White layer" /></td>
</tr>
<tr>
<td>Rotary</td>
<td><img src="image" alt="No White layer" /></td>
<td><img src="image" alt="Very faint WL" /></td>
<td><img src="image" alt="Faint WL" /></td>
</tr>
</tbody>
</table>
Current Work

Compare Tool Wear for Different Tool Materials

1. Utilizing 2 rotary tool holders
   - Rotary Technology Tool Holder
   - Mitsubishi Carbide Tool Holder

2. Utilizing 4 rotary insert tools
   - PCBN
   - CBN-TiN coated carbide
   - Si$_3$N$_4$
   - TiN coated carbide
Summary

1. Rotary & fixed tools show different surface integrity
   - Surfaces turned with rotary tool show lower tendency to form white layer

2. Model & experiments result in rotary tools providing lower cutting temperatures (~50°C for these conditions) vs. equivalent circular fixed tool cutting

3. Fixed tool observed to wear faster than rotary tool
Acknowledgement …

CATERPILLAR

Rotary Technologies Corporation

Nanomech

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