Surface Generation Mechanisms in Finish Hard Turning

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Overview

- Systematic investigation of surface generation mechanisms in finish hard turning
- Investigation of AISI 52100 and AISI 4340 as a function of cutting parameters and tool geometries
- Proposed work:
  - Finite Element simulation of hard metal machining:
    - A 2-D model to predict surface roughness, residual stresses and white layer formation
  - Experimental study to correlate surface integrity with functional properties
    - Fatigue and wear behavior of different hard turned components will be studied
AISI 4340 and AISI 52100: A comparative study

- Residual stresses, white layer formation and workpiece subsurface flow affect component behavior

- Thorough understanding of these effects is therefore necessary to maximize component life and performance

- AISI 52100 and 4340 differ significantly in percentage of carbon. Effect of this factor on surface generation mechanisms was sought to be determined
Experimental Work

- **Tools used:**

- **Workpiece Material:**
  - AISI 4340 bars, through hardened to ~ 57 R_c

- **Hard turning procedure**
  - Constant surface speed of 121.9m/min (400 SFPM)
  - Radial depth of cut: 0.254 mm (0.01 in)
  - Length of cut: 20.32 mm (0.8 in)
  - Feeds: 0.05, 0.10 and 0.15 mm/rev (0.002, 0.004 and 0.006 ipr)

- **Residual Stresses:**
  - X-ray diffraction method used

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<table>
<thead>
<tr>
<th>Edge Preparation</th>
<th>Nominal Value (µm)</th>
<th>Measured Value (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Hone</td>
<td>100-150</td>
<td>121.9 ± 7.6</td>
</tr>
<tr>
<td>Chamfer with Up-Sharp Edge</td>
<td>&lt;50</td>
<td>25.4 ± 12.7</td>
</tr>
</tbody>
</table>
**Results: White Layer, Chamfered Tool**

- No white layer for 0.05 and 0.10 mm/rev (0.004 and 0.006 ipr)
- No over-tempered layer detected for all feeds
- **52100 steel:**
  - White layer detected for 0.10 and 0.15 mm/rev (0.004 and 0.006 ipr)
  - Over tempered layer detected for all feeds
Results: White Layer, Chamfered Tool, AISI 52100

- Continuous white layer as well as over-tempered layer for 0.10 and 0.15 mm/rev (0.004 and 0.006 ipr) feeds
- Over-tempered layer for 0.05 mm/rev (0.002 ipr) feed

Longitudinal View of Continuous White Layer.
25.4 µm Chamfer. 0.15 mm/rev Feed. 57 HRC Workpiece
**Results: White Layer, Honed Tool**

- Continuous white layer for all feeds
- No overtempered layer detected
- **AISI 52100:**
  - White layer detected for all feeds
  - Over tempered layer detected for all feeds
Results: White Layer, Honed Tool, AISI 52100

- Continuous white layer as well as over-tempered layer for all feeds

Circumferential View of Continuous White Layer. 121.9 µm Hone. 0.15 mm/rev (0.006 ipr) feed. 57 HRC Workpiece.
Results: Workpiece Plastic Flow

- Chamfered tool and honed tool, 0.05 mm/rev
- Plastic flow detected for all values of feed, both edge preparations.
- AISI 52100:
  - No noticeable plastic flow for chamfered tool
  - Similar observations for edge honed tool
Results: Workpiece Plastic Flow, AISI 52100

Flow in Circumferential Direction. 121.9 μm Hone. 0.15 mm/rev (0.006 ipr) feed. 57 HRC Workpiece.

No Evidence Flow in Circumferential Direction. 25.4 μm Chamfer. 0.15 mm/rev (0.006 ipr) feed. 57 HRC Workpiece.
# Comparison of Microstructural Observations

<table>
<thead>
<tr>
<th>Test</th>
<th>52100</th>
<th>4340</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Optical</td>
<td>BSE</td>
</tr>
<tr>
<td>25.4 µm chamfer, 0.05mm/rev</td>
<td>Over tempered layer</td>
<td>Neg. Flow</td>
</tr>
<tr>
<td>25.4 µm chamfer, 0.10 mm/rev</td>
<td>Large, Intermittent White Layer</td>
<td>Neg. Flow</td>
</tr>
<tr>
<td>25.4 µm chamfer, 0.15 mm/rev</td>
<td>Continuous white layer</td>
<td>Neg. Flow</td>
</tr>
<tr>
<td>121.9 µm hone, 0.05 mm/rev</td>
<td>Continuous white layer</td>
<td>Flow</td>
</tr>
<tr>
<td>121.9 µm hone, 0.10 mm/rev</td>
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<td>121.9 µm hone, 0.15 mm/rev</td>
<td>Continuous white layer</td>
<td>Flow</td>
</tr>
</tbody>
</table>
**Results: Residual Stresses**

- Surface residual stress compressive in both directions for both cutting edge geometries
- **AISI 52100:**
  - Magnitudes of surface residual stress lower than AISI 4340
  - Magnitude of most compressive stress greater than AISI 4340
  - Depth at which peak compressive stress occurs larger
Discussion

- **White Layer Formation:**
  - Higher forces for chamfered and honed tools-higher temperatures, which leads to work material transformation
  - Maximum temperature reached in 4340 insufficient to cause overtempering

- **Workpiece Flow:**
  - Greater percentage of retained austenite in 4340 due to lower carbon content - greater plastic flow

- **Residual Stresses:**
  - Compressive nature of stresses due to white layer-volume expansion during transformation
  - Absence of over-tempered layer and greater plastic flow in 4340 lead to more compressive surface residual stresses
  - Differences in mechanical and thermal responses lead to different peak compressive stresses
Conclusions

- Steels of similar hardness behave differently in their mechanical, thermal and metallurgical responses.

- Absence of white layer in AISI 4340 steel at low feeds with a chamfered tool, and absence of over-tempered layer for all conditions.

- Evidence of plastic flow for all conditions studied in AISI 4340 steel.

- Surface residual stresses more compressive for AISI 4340 steel.

- Depth and magnitude of peak compressive stress greater for AISI 52100 steel.