Cutting UHS sheet with laser hardened tool steels

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Abstract

Laser hardened tools is becoming more popular in the industry. The process is an interesting alternative to induction, and flame hardening, when for instance hardening car body die components. This paper therefore reports Uddeholms AB’s studies on the performance of laser hardened cutting tools. A selective laser hardening operation has been made on the tools cutting edges. Some of the reasons why this type of selective hardening is used in the industry are: in the case when the part to be heat-treated is too large for the furnace, when only a small segment or area of the whole part needs the benefit in performance such a treatment offers and the overall cost saving the treatment provides by using inexpensive steels. Long-run cutting tests have been made with a number of tool steel grades with laser hardened cutting edges. The Docol 800DP sheet is used throughout the tests. The wear and failure mechanisms on these tool steel grades, as well as the appearance of the sheet blanks have been studied and taken into consideration in the evaluation process. From these tests, conclusions can be made regarding different tool steel grades suitability, durability and performance when cutting UHSS.

Key words: tool steel, laser hardening, wear

1. INTRODUCTION

Laser hardened tools are becoming more used in the industry. By using this type of localized heat treatment process and selectively laser harden only the cutting edges of a for instance trimming tool, instead of harden the whole part, one might reduce cost and lead time [Asnafi et al., 2004, Jonsson et al., 2008] if the tribosystem is correctly set up. Practical aspects that makes this localized heat-treatment beneficial is when for instance the part to be heat treated is too large for the furnace or only when a small area of the whole part needs the benefit in performance such a treatment offers [Miralles, 2003].

This paper reports Uddeholms AB’s studies on the performance of laser hardened cutting tools manufactured from different steel grades as well as the quality of the, Docol 800DP blanks, in long-run test consisting of 200 000 shots.

The cutting tools in this context are to be seen as a type of trimming tool. They are either soft annealed or pre-hardened and their hardness lever stretches from 200 - 415
HB. A steel grade provided by a competitor is also a part of the test matrix merely to widen the understanding of important characteristics of laser hardened tool steels when cutting UHS rather than an alternative option.

2. EXPERIMENTAL

2.1 Equipment and procedure
The type of press being used to perform the cutting-tests at Uddeholms AB, Hagfors, is an ESSA four pillar eccentric press, with 15 000 kg capacity and a stepless stroke rate between 100-600 strokes/min.

Long-run tests up to 200 000 strokes per tool steel combination has been performed in the press. The criteria for when to abort the test is set to either when the cutting tools stops producing blanks i.e. is not cutting the sheet of properly, or at the stipulated amount of strokes.

The stroke rate for the test is 200 strokes per minute and the feed rate is set to 8 mm. The cutting clearance is 5% or 0.05 mm, hence the sheet thickness 1 mm. The lower dead-end on the machine is set to –0.1 mm, i.e. the upper and lower cutting tool overlap with 0.1 mm before they go apart again and open up to give room for new steel sheet.

The wear of the cutting tools are measured with a Taylor-Hobson, Talysurf 4 surface measuring instrument, which makes use of a sharply pointed stylus to trace the profile of the surface irregularities. The wear is observed at 6 positions on the cutting edge of the tools; three on each tool (figure 3). Because of practical reasons and a limitation in the measuring machine to provide an adequate reference surface for this specific test, only one side on each tools cutting edge was measured.

The burr height is measured on 5 positions on the blanks with a mikrokator, an instrument for measuring differences in length, from CE Johansson, type 509-4.

The micro hardness profile is measured on the cross-section of the tool with a Matsuzawa MXT50 digital hardness tester; Load 200g, Vickers hardness. Measurement direction according to figure 2.

The laser hardening of the cutting tools has been carried out by Duroc Tooling, located at the Volvo Car Body Component area in Olofström. All the data regarding the laser hardening process, shown below, is provided by them:

A six axis jointed-arm-robot, Laserline LDL 4000, carrying a 4 kW diode laser with a 15 x 15 mm lens was used. The distance between the optics and the beam is 200 mm. The speed or feed rate of the laser beam along the cutting-edge is 4-5 mm/s and its angle, α, as defined in figure 1 is 70°. The laser is equipped with an integrated pyrometer to supervise and measure the temperature, on the surface, which exceeds 1000 °C.
Figure 1; Diagram displaying the laser speed and angle, \( \alpha \). The cutting motion is indicated by the arrow in the diagram to the left. The cutting tool, on top of the sheet, is called “upper cutting tool”, and the one below “lower cutting tool”.

Figure 2; The micro hardness measurements was carried out according to this example showing a micrograph of an etched (2% Nital reagent) cross-section of a cutting tool. The results from the measurement is to be seen in figure 4 and 5.

Figure 3; Wear measurements is performed on 3 positions on the upper cutting tool and 3 on the lower cutting tool.
2.2 Material

The tool steel grades used in the cutting tools are Uddeholms AB’s, which are forged, as well as a competitor grade which is continuous cast. Apart for this the different delivery conditions and bulk hardness levels are to be seen in table II.

The chemical analysis of the tool steel grades is seen blow in table I, as well as material data for the sheet steel, Docol 800DP (table III). The Docol 800DP is of UHS type and the width is 20 mm for this test. All the cutting tools are initially being ground with a CBN grinding wheel, to an average roughness (Ra) of about 0.4 µm and followed up with subsequent laser hardening of the cutting edges.

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caldie</td>
<td>0.70</td>
<td>0.25</td>
<td>0.45</td>
<td>4.93</td>
<td>0.065</td>
<td>2.41</td>
<td>0.47</td>
</tr>
<tr>
<td>Calmax</td>
<td>0.61</td>
<td>0.41</td>
<td>0.76</td>
<td>4.34</td>
<td>0.12</td>
<td>0.58</td>
<td>0.24</td>
</tr>
<tr>
<td>Carmo</td>
<td>0.60</td>
<td>0.33</td>
<td>0.72</td>
<td>4.25</td>
<td>0.15</td>
<td>0.52</td>
<td>0.25</td>
</tr>
<tr>
<td>Competitor</td>
<td>0.32</td>
<td>0.56</td>
<td>0.80</td>
<td>1.27</td>
<td>0.71</td>
<td>0.79</td>
<td>0.14</td>
</tr>
</tbody>
</table>

*Table I: Chemical composition of the studied tool steels in weight-%, measured with an optical emission spectrometer (OES).*

<table>
<thead>
<tr>
<th>Label</th>
<th>Steel grade</th>
<th>Condition</th>
<th>Bulk hardness [HB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calmax (200 HB)</td>
<td>Calmax</td>
<td>Soft annealed</td>
<td>200</td>
</tr>
<tr>
<td>Caldie (235 HB)</td>
<td>Caldie</td>
<td>Soft annealed</td>
<td>235</td>
</tr>
<tr>
<td>Carmo (270 HB)</td>
<td>Carmo</td>
<td>Pre-hardened</td>
<td>270</td>
</tr>
<tr>
<td>Carmo (350 HB)</td>
<td>Carmo</td>
<td>Pre-hardened</td>
<td>350</td>
</tr>
<tr>
<td>Caldie (350 HB)</td>
<td>Caldie</td>
<td>Pre-hardened</td>
<td>350</td>
</tr>
<tr>
<td>Competitor (415 HB)</td>
<td>Competitor</td>
<td>Pre-hardened</td>
<td>415</td>
</tr>
</tbody>
</table>

*Table II: An overview of the tool steels delivery harnesses, conditions and how they are labeled.*

<table>
<thead>
<tr>
<th>Sheet material</th>
<th>Condition</th>
<th>Thickness [mm]</th>
<th>R_p0.2 [MPa] min-max</th>
<th>R_m [MPa] min-max</th>
<th>A_80 [%] min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Docol 800DP</td>
<td>Cold-rolled, ferrite-martensitic</td>
<td>1</td>
<td>500-650</td>
<td>800-950</td>
<td>10</td>
</tr>
</tbody>
</table>

*Table III: The sheet steel grade Docol 800DP’s material data, supplied by the manufacturer, SSAB.*
3. RESULTS

All cutting tools managed to cut of the sheet in an efficient manner up to the stipulated amount of strokes without any complications, except the competitor grade. The burr build-up was too great due to the wear so the tools were unable to cut of the sheet.

3.1 Micro hardness

The laser hardenings hardness contribution on the cutting edges of the tools is substantial although its depth is somewhat limited (See also figure 2).

![Figure 4: Hardness profile for the soft annealed steels](image)

![Figure 5: Hardness profile for the pre-hardened steels.](image)
3.2 Burr height

The first burr height measurements starts after approximately 10 strokes and blanks are later on collected and measured at every 20 000. The “Competitor (415 HB)” grades burr was only measured up to 100 000 due to failure caused by wear. The burr build-up was too great to be able to continue to cut of the sheet (fig. 7).

Figure 6; Burr height of the Docol 800DP blanks, for the soft annealed steels

![Graph showing burr height for soft annealed steels](image)

Figure 7; Burr height of the Docol 800DP blanks, for the pre-hardened steels. The “Competitor (415 HB)” grade failed after 115 000 strokes, hence no values after 100 000 strokes.

![Graph showing burr height for pre-hardened steels](image)
3.3 Wear

The predominately wear mechanism is abrasive wear, other failure mechanisms apart from wear such as plastic deformation and chipping has also occurred on the cutting tools (figure 10). The wear graph (figure 9) displays the total amount of wear for the 3 position on each cutting tool.

![Wear graph after 200 000 strokes in Docol 800DP sheet. The “Competitor (415HB)” failed after 115 000 strokes and have therefore not been measured here.](image)
4. DISCUSSION

The hardness for the tool steels after laser hardening drops more sharply for the soft annealed grades and the hardness contribution the laser hardening provides stretches less deep than for the pre-hardened ones (fig. 4 and fig. 5). The “Competitor (415HB)” samples hardness stretches deeper than all the others but also drops somewhat steeper. The reason for the more modest maximum hardness for this grade is the, in comparison, low carbon content and the fact that the competitor is less alloyed than the Uddeholm grades (table I). The sudden temporary hardness drop for the “Caldie (350 HB)” sample (fig. 5) is probably due to inefficient heat treatment which is apparent when studying the micrograph below (fig. 11).

Figure 11; Etched micrograph (2% Nital reagent), displaying the heat affected zone – HAZ – on a cross-section of the laser hardened “Caldie (350 HB)”.

10 % of the sheet material thickness is often said to be the height limit for burr [Jonsson, 2010]; which is 100 µm in our case; in other words the burr is kept at a low
level up to 80 000 shots. (fig. 6 and fig. 7). “Calmax (200 HB)” has a prominent increase in burr height after 140 000 shots.

It appears that “Competitor (415HB)” is getting plastically deformed relatively heavily almost instantly, hence the quite high burr height (fig. 7). The burr progresses along with the increasing tool wear until the point the cutting tool stops producing blanks properly (fig. 12). Although the “Competitor (415 HB)” has the highest bulk hardness it is apparent that the one major limiting factor, when it comes to tool life in this case, is the surface hardness on the cutting edge. Although the “Competitor (415 HB)” is laser hardened in the same manner as the other tool steels it doesn’t reach up to a hardness high enough to be able to withstand the strains from cutting the Docol 800 DP UHS sheet.

Plastic deformation has not been observed for any of the steels cutting edges with hardness > 700 MHV0.2.; Note that this might not always be the case for more demanding, more complex types of cutting processes than this one.

Figure 12; “Competitor (415 HB)” after 115 000 strokes: Plastic deformation in combination with abrasive wear is apparent on both the micrograph to the left and the corresponding wear measurement profile to the right.

The wear rate (fig. 9) shows quite even and low amounts of tool wear. “Competitor (415 HB)” could not be compared at the same number of strokes (200 000) since failure occurred at 115 000, but it is apparent that the grade showed an excessively higher amount of wear by studying the blanks (fig. 8) and the LOM picture (fig. 10).

The LOM pictures in figure 10, is taken on the lower cutting tool because its edge appearance influences the burr on the sheet the most. The cutting edges are rounded slightly by abrasive wear and have an even appearance, which also is reflected in the appearance of the blanks in figure 8.

The laser speed is a parameter that also might influences the abrasive wear resistance significantly [Surzhenkov et al., 2010] The “Caldie (235 HB)” has chipped somewhat which also shows on the blank in fig. 8. Worth noticing is that this sample have the lowest surface hardness of the Uddeholm grades (fig. 4). This might affected it negatively in the tribosystem concerning the abrasive wear [Axén, 1993].
5. CONCLUSIONS

All the laser hardened tool steels from Uddeholms AB performed excellently in this test, cutting Docol 800DP UHS sheet. The competitor’s role was somewhat prejudiced but provided useful information of important aspects needed when cutting UHSS. The following conclusions can be drawn from this test:

- Laser hardening should preferably be executed on pre-hardened condition.
- The surface hardening of the cutting edges should be about 800 HV or more to suppress plastic deformation and abrasive wear.
- The bulk hardness of the tool steel is less important for the outcome.
- Sufficient carbon content is necessary to provide an adequate hardenability in the heat affected zone.

6. ACKNOWLEDGEMENT

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REFERENCES


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