STEEL FOR PRESS TOOLS

Blanking of Ultra High Strength Steel Sheet

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Abstract

The trend within the automotive industry today is to increase the safety level and at the same time reduce fuel consumption and emission. One way of doing this is to lower the weight by reducing the material thickness of parts used to manufacture the car. In fact, more and more parts used today are being made from thinner but stronger steel sheet. The mechanical properties of the new ultra high strength sheet materials used enable the safety level to remain unchanged or to be improved even if the thickness of the steel sheet is reduced.

The tensile strength of ultra high strength steel sheet can be up to 1400 MPa (203 ksi). A work material with such high tensile strength places very high demands on the tools used and tool steels used to manufacture them. The tool user must be aware of this when ordering tools for making parts from such sheet. All links in the chain must be involved to ensure an optimal productivity. Up to now very little information on blanking of high strength steel sheet has been available. For this reason, some investigations were started in order to gather some basic information regarding suitable tool steel grades, hardness levels, cutting clearances and suitable types of coatings for the tools. The results from these tests and some recommendations for blanking ultra high strength steels are presented.
INTRODUCTION

The results presented are based on investigations made in a joint project with SSAB Tunnplåt AB in Borlänge, Sweden. The punchability of two of their UHS (UHS= Ultra High Strength) steel sheet grades Docol 800 DP and Docol 1400 DP have been investigated so far. The tensile strengths of these materials are 800 MPa and 1400 MPa respectively.

TEST PERFORMANCE

EXPERIMENTAL

All the laboratory blanking tests were made using an eccentric press with 15 000 N press force. The thickness of the strip used was 1.0 mm. The aperture of the die used was always 10 mm diameter and the punch diameter was changed to give the required clearance. The punches were circumferentially ground to a surface roughness of Ra 0.2 µm. The punch speed used was 200 strokes/minute and the number of strokes made were around 200 000 per test. All the blanking tests were made without any lubrication. The parameters investigated were as follows:

- Cutting clearance and its influence on the blanked edge condition
- Burr height on parts
- Wear distribution on the punch
- Wear type

Wear measurements on the punches were made using a Talysurf 4 device with a modified pick-up. Four positions around the punch were measured and an average of these values was taken. The (two-dimensional) unit of wear is expressed in µm². The set-up is shown schematically in Fig. 1.

TOOL STEELS

The analyses and hardness of the tool steels used in the investigation are given in Table 1. CALMAX is a matrix steel (i.e. contains no primary carbides). SVERKER 21 and SLEIPNER are higher alloyed conventional tool steels with high primary carbide contents. VANADIS 4 and VANADIS 6 are high alloyed and carbide rich powder metallurgical (PM) tool steels.
with a much more uniform dispersion of carbides and much smaller carbides compared to conventionally produced tool steels. CALMAX, SVERKER, SLEIPNER and VANADIS are trade names of Uddeholm. VANADIS 4 was also tested with three PVD coatings and one CVD coating. The coatings were produced by commercial coating companies.

Table 1. Tool steels and hardness levels used for the punches

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>AISI</th>
<th>W.-Nr.</th>
<th>C%</th>
<th>Si%</th>
<th>Mn%</th>
<th>Cr%</th>
<th>Mo%</th>
<th>V%</th>
<th>Hardness(HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALMAX</td>
<td></td>
<td>1.2358</td>
<td>0.6</td>
<td>0.4</td>
<td>0.8</td>
<td>4.5</td>
<td>0.5</td>
<td>0.2</td>
<td>58</td>
</tr>
<tr>
<td>SVERKER 21</td>
<td>D2</td>
<td>1.2379</td>
<td>1.55</td>
<td>0.3</td>
<td>0.4</td>
<td>11.8</td>
<td>0.8</td>
<td>0.8</td>
<td>58, 60</td>
</tr>
<tr>
<td>SLEIPNER</td>
<td>—</td>
<td>—</td>
<td>0.9</td>
<td>0.9</td>
<td>0.5</td>
<td>7.8</td>
<td>2.5</td>
<td>0.45</td>
<td>60</td>
</tr>
<tr>
<td>VANADIS 4</td>
<td>—</td>
<td>—</td>
<td>1.5</td>
<td>1.0</td>
<td>0.4</td>
<td>8.0</td>
<td>1.5</td>
<td>4.0</td>
<td>58, 60, 62</td>
</tr>
<tr>
<td>VANADIS 6</td>
<td>—</td>
<td>—</td>
<td>2.1</td>
<td>1.0</td>
<td>0.4</td>
<td>6.8</td>
<td>1.5</td>
<td>5.4</td>
<td>60</td>
</tr>
</tbody>
</table>

WORK MATERIAL

The first of the two sheet steel materials tested was Docol 1400 DP, which has a tensile strength level of 1400 MPa. The microstructure consists of 100% martensite. The second material tested was Docol 800 DP, which has a tensile strength level of 800 MPa. The microstructure of Docol 800 DP consists of 60% martensite and the rest is ferrite. Measured values and typical values for the chemical analyses and mechanical properties are given in Tables 2 and 3.
Table 2. Chemical analyses of the work materials

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>C%</th>
<th>Si%</th>
<th>Mn%</th>
<th>P%</th>
<th>S%</th>
<th>Al%</th>
<th>Nb%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Docol 1400 DP</td>
<td>0.17</td>
<td>0.53</td>
<td>1.60</td>
<td>0.008</td>
<td>0.001</td>
<td>0.048</td>
<td>0.016</td>
</tr>
<tr>
<td>(Typical values)</td>
<td>(0.17)</td>
<td>(0.50)</td>
<td>(1.60)</td>
<td>(0.015)</td>
<td>(0.002)</td>
<td>(0.040)</td>
<td>(0.015)</td>
</tr>
<tr>
<td>Docol 800 DP</td>
<td>0.12</td>
<td>0.22</td>
<td>1.46</td>
<td>0.015</td>
<td>0.0025</td>
<td>0.036</td>
<td>0.02</td>
</tr>
<tr>
<td>(Typical values)</td>
<td>(0.12)</td>
<td>(0.20)</td>
<td>(1.50)</td>
<td>(0.015)</td>
<td>(0.002)</td>
<td>(0.040)</td>
<td>(0.015)</td>
</tr>
</tbody>
</table>

Table 3. Mechanical properties of the work materials

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Yield strength $R_{p0.2}$ MPa</th>
<th>Yield strength $R_{p0.2} + BH^1$ MPa</th>
<th>Tensile strength $R_m$ MPa</th>
<th>Elongation $A_{80}$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Docol 1400 DP</td>
<td>1269</td>
<td>—</td>
<td>1494</td>
<td>(3)</td>
</tr>
<tr>
<td>(Typical values)</td>
<td>(1150–1450)</td>
<td>(1300)</td>
<td>(1400–1600)</td>
<td>(3)</td>
</tr>
<tr>
<td>Docol 800 DP</td>
<td>555</td>
<td>—</td>
<td>797</td>
<td>(8)</td>
</tr>
<tr>
<td>(Typical values)</td>
<td>(500–650)</td>
<td>(650)</td>
<td>(800–900)</td>
<td>(8)</td>
</tr>
</tbody>
</table>

$^1$ With bake hardening effect
RESULTS FOR THE 1400 MPA WORK MATERIAL

FIRST TEST SERIES

The first test series was basically a preliminary investigation to get some feeling for the behaviour of the work material during blanking and its effect on the tooling used. The tool steels selected were CALMAX, SVERKER 21 and VANADIS 4, all hardened and tempered to 58 HRC. The punches were made from 20 mm diameter bar material, i.e. they had the fibre orientation parallel to the punch axis. In order to be able to compare results with the results from former tests with mild steel, a die clearance of 6% per side of the strip thickness was chosen. The results from the punch wear measurements are shown in Fig. 2 and each curve represents average values from two tests. From mild steel and up to 500–600 MPa material, a normal range for the punch wear is about 1000–4000 µm² [1, 2, 3]. The result from this first test series with the ultra high strength steel Docol 1400 DP showed as expected that there is a much higher punch wear. The tests with punches made of CALMAX and SVERKER 21 were stopped after 140 000 strokes because of the very high tool wear. Punches made of VANADIS 4 were able to reach 200 000 strokes but the tool wear of around 15 000 µm² was still rather high. However, it is not only the amount of wear that varies but also the type of wear. Figure 3 shows the edge and prismatic surface condition for punches made of the three different type of tool steels after 140 000 strokes.
With CALMAX punches the wear was rather low at the beginning but it increased dramatically after around 100 000 strokes because of fatigue crack development and resultant chipping on the prismatic surface about 0.3 mm from the cutting edge. The wear is relatively low as long as no chipping occurs. With punches made of SVERKER 21 the wear is more located on the cutting edge and there is a lot of chipping. Here the abrasive wear on the prismatic surface is much smaller than with CALMAX punches due to the presence of the hard carbides. With the powder metallurgical tool steel VANADIS 4, there was abrasive wear on the prismatic surface but there was no sign of chipping on the cutting edge. The conclusions from the first test series were as follows:

- The PM tool steel VANADIS 4 gave the best results, i.e. wear but no chipping
Steel for Press Tools

The punch wear rate is higher compared to that for softer steel

Fatigue cracks can be seen on the prismatic surface of punches made of CALMAX and SVERKER 21 after 140,000 strokes

SECOND TEST SERIES

The aim of the second test series was to reduce the punch wear by increasing the hardness of the punches from 58 HRC to 60 HRC. CALMAX was not included in the second test series because its maximum achievable hardness is around 58 HRC. Two other tool steels, VANADIS 6 and SLEIPNER were introduced. VANADIS 6 is similar to VANADIS 4 but it is more wear resistant. SLEIPNER is similar type of material to SVERKER 21 but it has a better resistance to edge chipping. All the punches for this test series were made from flat bar material 250 × 80 mm, i.e. they had a fibre orientation transverse to the punch axis as the latter orientation is more common when producing punches from flat tool steel bar. In all cases the die clearance was 6% per side of the sheet thickness. VANADIS 4 punches were tested not only at 60 HRC but also at 62 HRC. The punch wear after 200,000 strokes with the punch hardness 60 HRC can be seen in Fig. 4.

![Figure 4. Punch wear after 200,000 strokes for the second test series (punch hardness 60 HRC)](image)

With increased punch hardness from 58 to 60 HRC, the punch wear with VANADIS 4 went down from 25,000 µm² to around 10,000 µm² – see Fig. 5. It can also be seen that the lowest wear on the VANADIS 4 punches is
achieved with the hardness 60 HRC. Note that the VANADIS 4 punches at 58 HRC used in the first test series and with fibre orientation parallel to the punch axis showed less wear than the VANADIS 4 punches at 58 HRC with a transverse fibre orientation which were produced from a larger flat steel bar.

![Figure 5. Effect of punch hardness on the tool wear for VANADIS 4 (second test series)](image)

The wear on the SLEIPNER punches was less than with the SVERKER 21 punches, even though the wear with the SVERKER 21 punches at 60 HRC was less than for the SVERKER 21 punches tested at 58 HRC. The VANADIS 6 punches showed the lowest wear rate but one of the two punches tested chipped badly and it was not possible to measure the wear. Fatigue cracks are starting to appear on the prismatic surface of all punches after about 80–100 000 strokes. The conclusions from the second test series were as follows:

- VANADIS 6 showed the lowest wear rate but was not reliable because one of the tools chipped badly
- VANADIS 4 showed the most reliable performance but the wear rate was still considered to be too high
- SLEIPNER gave a more reliable wear type with less edge chipping than SVERKER 21
- 60 HRC seems to be the optimal punch hardness with a die clearance of 6%
Fatigue cracks starting to occur on the prismatic surface of all punches after about 80–100 000 strokes

THIRD TEST SERIES

The aim of this series was to find the optimal die clearance and to test some coated punches. Because of the earlier good results, VANADIS 4 at 60 HRC was selected as the punch material for this series. Three different die clearances were tested – 6%, 10% and 14% of the sheet thickness. The results with 6% clearance with uncoated punches are those obtained in the second test series. The types of coatings tested were one CVD type (TiC) and three PVD types (TiCN, TiAlN and TiN).

The effect of die clearance on punch wear is shown in Fig. 6. With a die clearance of 10% of the sheet thickness the punch wear is below 6000 µm after 200 000 strokes. With the larger clearance of 14%, there is a tendency to more edge chipping and hence higher wear rate. The reason could be higher stresses in the punch due to more bending force over the cutting edge of the punch. The chipped out particles from the cutting edge result in severe gouging on the prismatic surface – see Fig. 7.

The coated punches did not perform particularly well, either with a 6% die clearance or with a 10% die clearance – see Fig. 8. No tests were made with a 14% clearance. The coatings came off after a certain number of punch strokes, at the cutting edge or along fatigue cracks in the prismatic surface. The fatigue cracks appeared first after 80–100 000 strokes. The conclusions from the third test series were as follows:

![Figure 6. Punch wear after 200 000 strokes in Docol 1400 DP with different die clearances)
Figure 7. Typical appearance of punch wear with 14% die clearance

Figure 8. Typical wear appearance on punches coated with four different coatings after 100,000 strokes
The optimal die clearance for 1 mm thick Docol 1400 DP appears to be 10%.

Coated punches did not improve the punch performance with Docol 1400 DP.

RESULTS WITH THE 800 MPA WORK MATERIAL

FIRST TEST SERIES

The aim of the first test series was to check the influence of die clearance on the punch wear when blanking the 800 MPa material. VANADIS 4 at 60 HRC was chosen as the tool material – this choice was based on the good results obtained for the 1400 MPa material. The punches were produced from flat bar $250 \times 80$ mm and with laying fibre orientation. The die clearances tested were 6%, 10% and 14% of the sheet thickness. The results, along with those for the 1400 MPa material are shown in Fig. 9.

![Graph showing punch wear with different die clearances for 800 Mpa and 1400 Mpa material](image)

Figure 9. Punch wear with different die clearances for 800 Mpa and 1400 Mpa material

The results show that the lowest punch wear was achieved by using the largest die clearance (14%) and that the wear rate is much lower than when blanking the 1400 MPa material. However, after examination of the worn punches in a scanning electron microscope, it was discovered that there was pick-up of the work material on the punches especially when a die clearance of 6% was used. This can be seen in Fig. 10. The pick-up when blanking the Docol 800 DP material is due to the fact that this material contains softer ferrite. The pick-up (or galling) on the punches would also be included in the
wear measurement made using the Talysurf instrument – it would manifest itself as a ‘negative wear’ and falsify the true wear measurement. Thus, it is more likely that the true punch wear as a function of die clearance should be as illustrated in Fig. 9. The conclusions from the first test series were as follows:

- The wear rate with the 800 MPa material is lower than for the higher strength 1400 MPa material
- The wear rate decreases with increasing die clearance
- More pick-up (galling) occurs during blanking with smaller die clearances most likely because of the presence of ferrite in the work material

SECOND TEST SERIES

Coated punches may work well in Docol 800 DP because of the type of wear experienced and the absence of microcracks and chipping along the cutting edge. Earlier experiences have shown that with a 350 MPa work material containing ferrite, a coating on a VANADIS 4 punch lowers the tool wear dramatically from 3200 $\mu$m$^2$ to 800 $\mu$m$^2$ after 150 000 strokes [1]. In order to see if a coating has any positive effect on the tool performance VANADIS 4 at 60 HRC was tested with a PVD coating with 10% die clear-
ance. Good result was also achieved with the 800 MPa material as can be seen in Fig. 11, no galling was achieved with the coated punch.

![SEM photos of uncoated and coated VANADIS 4 punch after 200,000 strokes](image)

**Figure 11.** SEM photos of uncoated and coated VANADIS 4 punch after 200,000 strokes

Docol 800 DP

The conclusions from the second test series were as follows:

- A coating prevents galling on the punch when working in Docol 800 DP

**Burr Formation and Edge Appearance**

Very often a maximum allowed burr height is the criterion used to decide when a blanking punch should be reground. Therefore, during the blanking tests made, the height of the burr on the blanked out slugs was measured at intervals of 50,000 strokes. Eight measurements of the burr height were made around the edge of the slug and an average of these values was calculated. A typical maximum average value from former punch tests in mild steels was 60 µm. The two ultra high strength materials in this investigation, Docol 800 DP and Docol 1400 DP, gave much lower burr heights. At the start of the tests the burr height was 10–20 µm. It then increased slowly to 20–30 µm until the tests stopped after 200,000 punch strokes, see Fig. 12.

Changing the die clearance or punch hardness did not influence the burr height for the UHS materials. However, there was a difference between the two work materials concerning burr formation. The burr formation in Docol 1400 DP was more uneven along the edge as can be seen in Fig. 13. This
Figure 12. Measured burr height for different work materials

Figure 13. Typical burr formation with the 1400 MPa materiel
unevenness resulted in more scatter when measuring the burr height but the average burr height was kept the same for both materials.

The edge formation was different with different cutting clearance. With a smaller cutting clearance as 6% of the strip thickness the vane becomes smaller. However, the fracture zone was quite rough most likely due to high shear stresses, which could also be seen on the higher cutting forces with a 6% cutting clearance. With a bigger cutting clearance, the fracture zone was very smooth; indicating a more brittle and easier propagation of the fracture, see Fig. 14. Following conclusion could be drawn:

- The burr height does not seem to be a problem when punching in UHS sheet
- The burr formation was more uneven in the 1400 MPa material than in the 800 MPa material
- Different die clearances did not affect the burr height but the appearance of the cutting edge of the sheet material

**DISCUSSION**

The tests made to date have demonstrated that it is perfectly possible to blank ultra high strength steel sheet material. They have also clearly shown that working with such materials places higher demands on the tool steels used for the blanking tooling, especially with Docol 1400 DP. The tool steels used should have a good combination of abrasive wear resistance, ductility (to prevent crack formation) and toughness (to prevent crack propagation).
The design of the tools is also very important. The higher cutting forces during the punching operation can easily lead to breaking off of the punch head e.g. if adequate radii are not used or if the head diameter is too small. Other important aspects are the stability of the press and the blanking die set. Another factor to consider is that the noise level is higher when blanking high strength materials. It may be necessary to insulate the press for environmental health reasons.

Other types of high strength sheet steels are hardened carbon steels. The carbon steels have high carbon content and consequently they contain hard carbides. These hard carbides make the carbon steels more abrasive and that result in more tool wear than when blanking the low carbon dual phase and ultra high strength materials presented in this paper.

CONCLUSIONS

Two work materials have been examined for punchability. The two work materials are of low carbon dual phase and high strength type. The two strength levels are 800 MPa and 1400 MPa. The results from the investigations presented in this paper gave following conclusions:

- The punch wear rate is higher compared to that for softer sheet steel
- The wear rate with Docol 800 DP is lower than for Docol 1400 DP
- Pick-up (galling) occurs during blanking in Docol 800 DP probably because of the presence of ferrite in the work material
- Fatigue cracks starting to occur on the prismatic surface of the punches after about 80–100 000 strokes when punching in Docol 1400 DP
- Coated punches did improve the punch performance in Docol 800 DP but not in Docol 1400 DP
- The burr formation was small after punching both tested work materials

Coated tools have not improved the punch performance when punching with the highest strength 1400 MPa material but further investigations are planned. Coatings work better with the 800 MPa material firstly because this work material can cause pick-up (galling) and secondly because no microcracks were observed on the prismatic surface of the punches tested.
ACKNOWLEDGMENTS

We would like to take this opportunity to extend our sincere thanks to SSAB Tunnplåt AB, Borlänge, Sweden for supplying the steel sheet for the tests and for the many useful discussions we have had during the testing period.

REFERENCES

[1] Uddeholm internal report FM86-274-10
[3] Uddeholm internal report FM88-221-1