NEW TRENDS IN THIN COATINGS FOR SHEET-METAL FORMING TOOLS.

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Abstract Thin coatings deposited on forming tools are used to optimize the forming process and to increase the life of the tool. The main properties required are the reduction of friction as well as improved resistance against abrasive and/or adhesive wear. Furthermore the bonding strength between coating and substrate is an important fact for a successful application.

DLC-coatings (Diamond-Like Carbon) show very good results in aluminium sheet forming processes. Due to the low friction coefficient and the high resistance against adhesive wear the WC/C-coating (~1200 HV), which is one of the DLC-coatings, distinctly reduces the build up of aluminium on the tool surface. The new USB-coating, deposited by CVD, has been created for sheet-metal forming of high-strength steels. With a high surface hardness of ~3500 HV and low internal stresses the USB-coating combines the high abrasive wear resistance of a standard TiC-coating with an improved bonding strength between coating and substrate.

INTRODUCTION

With sheet-metal forming tools the automotive industry produces body and structural parts by deep drawing, braking and/or blanking. In addition to mechanical properties, like hardness, compressive strength, tensile strength or toughness, the tools should show a sufficient resistance to tribological loads during production.
Often thin CVD- or PVD-coatings are deposited on sheet-metal forming tools to increase the tool life or to improve the forming process. In Fig.1 a CVD-coated sheet-metal forming tool is shown.

The requirement of the automotive industry for lightweight construction parts has been followed by the development and introduction of new sheet-metal materials like aluminium or high-strength steels. Figure 2 gives an overview on the high-strength sheet-metal materials, developed in the last years. Coming from the standard steel grades DC04-DC06, high-strength interstitial-free (IF) steels, bake-hardening (BHZ) steels, phosphorus-alloyed (PHZ) steels and microalloyed (MHZ) steels are well known for sheet-metal materials with an improved strength. To reach a tensile strength between 500 and 1400 N/mm², high-strength steels, like dualphase (DP) steels, transformation induced plasticity (TRIP) steels, complexphase (CP) steels or
martensite phase (MS) steels, have become more common over the past few years.

**WEAR REQUIREMENTS**

Due to the change in sheet-metal material the required properties of the forming tool have been specialized, too. E.g., blanking punches used for high-strength steel sheets have to reveal a high hardness as well as a high toughness. Therefore the application of powdermetallurgical tool steels is often the only alternative.

The tribological loads of the tool surface are also influenced by the sheet-metal material. In Fig. 3 typical wear shapes at sheet-metal forming tools are shown. Adhesive wear can be observed frequently in combination with aluminium sheets or austenitic steel sheets, whereas abrasive wear appears...
for example in combination with high-strength steel sheets or scaled sheets. To reduce adhesive wear, the chemical junctions between tool surface and sheet metal have to be prevented. Thin coatings with a low friction coefficient and a low surface roughness are very effective to avoid adhesive wear.

![Diagram of adhesive and abrasive wear](image)

*Figure 3.*

The resistance to abrasive wear increases with the hardness of the tool. To enhance the hardness of the surface a lot of treatments are known. Usual treatments for sheet-metal forming tools are listed in Fig. 4. With nitriding the surface hardness of a standard tool steel (1.2379 / D2) can be improved from 750 HV to max. 1300 HV. Hard material coatings like the physical vapour deposited (PVD) TiN- coating or the chemical vapour deposited (CVD) TiC-coating are characterized by a distinctly higher hardness of $\sim 2300$ HV respectively $\sim 3500$ HV [1]. With carbon coatings, developed in the past few
years, the hardness of diamond ($\sim 10000 \text{ HV}$) can be reached theoretically [2]. Certainly the brittleness of such carbon coatings is very high.

**STANDARD COATINGS**

As above mentioned thin hard material coatings deposited by the PVD- or CVD-process are usual to improve the wear resistance of sheet-metal forming tools. Which type of coating process is applied, depends on the required properties as well as on the required dimensional tolerance. Due to the high CVD-process temperature of approx. 1000 °C a subsequent vacuum heat treatment is necessary. Therefore a possible change in dimension must be considered. The PVD-process temperatures are distinctly lower (200 – 450 °C). A tool, which has been heat treated inclusive tempering in the range of secondary hardness ($> 500 \text{ °C}$), can be PVD-coated without any changes.
in dimension. On the other hand the bonding strength between coating and substrate is much higher for CVD-coatings than for PVD-coatings [3, 4].

![Diagram showing different types of coatings and their properties](image)

**Figure 5.**

In Fig.5 standard hard material coatings by CVD and PVD are compared. Coming from the classical CVD-TiC-coating, which is characterized by a silver colour, a hardness of \(\sim 3500\) HV and a thickness of 6 - 9 \(\mu\)m, the CVD-Sandwich(TiC/TiN)-coating was developed to increase the adhesive wear resistance (e.g. austenitic steel sheets) as well as to underline by the golden surface colour of TiN that the tool is coated. Another development is the CVD-Multilayer-coating, comprising numerous, thin layers of TiC and TiN. With very low internal stresses and therefore a high toughness the CVD-Multilayer-coating obtains excellent results at stamping or coining tools. TiN can be called as the standard PVD-coating. Certainly with a hardness of \(\sim 2400\) HV and a thickness of 2 - 4 \(\mu\)m the properties of PVD-TiN are mostly insufficient for sheet-metal forming tools. For that reason often the
harder PVD-TiCN-coating (∼3000 HV) or the thicker PVD-CrN-coating (6 - 9 µm) are used. Furthermore the PVD-CrN-coating reveals an improved adhesive wear resistance in combination with aluminium sheets. A sufficient bonding strength between substrate and coating is one of the important points for PVD-coated tools. With increasing PVD-process temperature the bonding strength rises distinctly. In Fig. 6 the results of scratch tests at PVD-coated specimens are compared. While the low temperature PVD-coating is characterized by large-sized deposit flaking, the PVD-coating at 450 °C shows a good bonding strength.

A high hardness of the mentioned hard material coatings is decisive for abrasive wear resistance. On the other hand a low friction coefficient is an important factor against adhesive wear. Both information, hardness and friction coefficient at dry friction against steel, can be taken from Fig. 7.
DLC-COATINGS

Carbon is a coating material which has become more common over the past few years. Carbon coatings are characterized by an extreme low friction coefficient. Depending on the chemical bonding structure a friction coefficient between 0.01 and 0.2 can be observed at dry friction against steel. A classification of the different carbon coatings is given in Fig. 8. The diamond coatings (8000 - 10000 HV) show a crystalline, respectively a semicrystalline structure with sp3(diamond)-junctions, whereas the diamond-like carbon (DLC) coatings (800 - 6000 HV) have an amorphous structure. The hardness of the DLC-coatings is influenced by the ratio of sp3(diamond)-junctions and sp2(graphite)-junctions as well as by hydrogen or metal addition. Due to this the DLC-coatings can be divided in pure amorphous carbon (a-C) coatings, amorphous carbon/hydrogen (a-C:H) coatings and amor-
phous carbon/hydrogen/metal (Me-C:H) coatings. With increasing hardness the internal stresses and the brittleness of the different carbon coatings grow [5, 6]. Therefore the carbon coatings with a hardness above 2500 HV are not usual for sheet-metal forming tools at present.

An interesting DLC-coating for aluminium sheet forming processes is the WC/C-coating, Fig.9. Belonging to the Me-C:H coatings, the WC/C-coating distinctly reduces the build-up of aluminium on the tool surface, due to the low friction coefficient and the resistance against adhesive wear. With a hardness of about 1200 HV, the WC/C-coating reveals a higher wear resistance than the lubrication coatings MoS$_2$ or WS$_2$. The 1 - 4 $\mu$m thick PVD-WC/C-coating is normally supported by a CVD-TiC or a PVD-CrN hard material coating deposited on the substrate first.
USB-COATING

The scope to develop the new CVD-USB-coating was to reduce the internal stresses without decreased surface hardness in comparison to the classical CVD-TiC-coating. The different thermal expansion coefficients of the substrate and the hard material coating influence decisively the build-up of internal stresses after the CVD-coating process. As shown in Fig.10 the thermal expansion of the substrate material (tool steel 1.2379 / D2) is much higher than the thermal expansion of CVD-TiC-coating. For this reason high internal compressive stresses are build up in the hard material coating. In comparison to TiC the thermal expansion of TiN is near the thermal expansion of the tool steel. Due to the TiN-startlayer of the new created CVD-USB-coating a more homogenous gradient in internal stresses as well as in hardness appears. Starting from the hardened substrate with \( \sim 750 \) HV, a TiN-layer with \( \sim 2400 \) HV follows before with the outer TiC-layer a surface hardness of \( \sim 3500 \) HV can be observed, Fig.11. The CVD-USB-coating is very attractive for sheet-metal forming tools, where the classical CVD-TiC-coating fails by flaking. With the combination of high abrasive wear resistance and reduced internal stresses, respectively improved bonding strength between coating and substrate, the application of the new CVD-USB-coating can be seen in high-strength steel forming processes.

SUMMARY

For sheet-metal forming tools often thin coatings are deposited to increase the tool life or to improve the forming process. With new coating systems the trends in sheet-metals required for lightweight construction parts can be encountered. While the WC/C-coating shows excellent results at aluminium forming processes, the forming of high-strength steels can be the favourite of the USB-coating. Nevertheless thin coatings are only one factor in tool life. Figure 12 presents a lot of other influences, which have not to be neglected.

REFERENCES


PVD-WC/C

Hardness: ~1000-1200 HV
Thickness: 1-4 μm
Structure: Surface layer deposited on CVD-TiC or PVD-CrN
Application: ⇒ forming of Aluminium
             ⇒ low friction coefficient, excellent dry run properties

Figure 9.

<table>
<thead>
<tr>
<th>material</th>
<th>1.2379</th>
<th>TiN</th>
<th>TiC</th>
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<tbody>
<tr>
<td>hardness</td>
<td>650-750 HV</td>
<td>2400 HV</td>
<td>3500 HV</td>
</tr>
<tr>
<td>thermal expansion coefficient</td>
<td>10.1·10⁻⁶ / °C</td>
<td>9.3·10⁻⁶ / °C</td>
<td>7.4·10⁻⁶ / °C</td>
</tr>
</tbody>
</table>

**TiC-coating**

- coating process temperature
- room temperature
- stress build-up

**USB-coating**

- coating process temperature
- room temperature
- stress build-up

Advantage of the CVD-USB-coating

Figure 10.
CVD-USB

Hardness: \(\sim 2400-3500 \text{ HV}\)
Thickness: 6-9 \(\mu\text{m}\)
Structure: Multilayer
Application: ⇒ forming of high-strength materials
              ⇒ improved bonding strength, high surface hardness

Figure 11.
Figure 12.