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Hard Thin Film Coatings for Forming Tools

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Hard thin film surface coatings are often applied to cold work tool steel forming dies. The coatings are usually extremely hard ceramics with a thickness of only a few microns, but are particularly effective in improving the performance of dies by resisting wear, scoring and adhesion. Only a few types of coatings are effectively used in stainless steel metal forming industry. The article will discuss the major coatings used and basic guidelines for preparing the die for surface coating.

Introduction

Thin film coatings are typically carbide or nitride ceramic type coatings of thickness 10 µm or less. The coatings are either deposited onto the surface of a tool steel, or in some cases are also diffused onto and into the tool steel. Not withstanding their thickness, the coatings are particularly effective in resisting various forms of wear, and will assist in the sustained production of a quality component. Scrap is minimized and downtime is significantly reduced.

Various methods are available to significantly harden the surface of a steel as shown in figure 1. However, the thin film coatings predominantly used nowadays in the stainless steel metal forming industry are applied by Physical Vapour Deposition (PVD), Chemical Vapour Deposition (CVD) and Thermoreactive Diffusion (TD) [1]. The coatings are extremely hard (± 2300 HV, 3300 HV and 3500 HV respectively) and provide a slippery, highly wear resistant surface. In comparison, conventional tool steels cannot be hardened over ± 900 HV as also shown in figure 1.

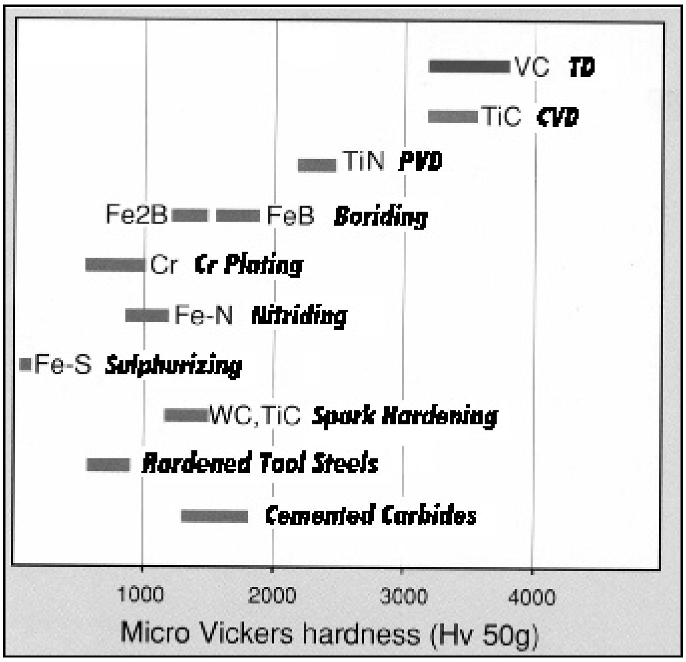

Figure 1 : *Comparison of various hard surface layers [2]*

The reasons for implementing coatings may be varied i.e. they aren't limited to a particular type of manufacturing e.g. high volume runs, and they should rather be considered as unique problem solvers that assist production. The effectiveness of the coating is however highly dependent on the substrate material and its condition, and in order to extract maximum performance from the coating, the correct combination of tool steel, pre-processing condition, heat treatment and, in some cases, post coating heat treatment must be performed [1].

PVD Coating

The PVD coating is applied at low temperature (200°C~550°C) in specialized equipment and mostly a thin layer of gold coloured titanium nitride (TiN) is deposited onto the steel. Other types of coatings may also be obtained from this process but they have not shown a significant advantage over TiN in forming applications [3].

Several pre-coating processes have to be followed prior to coating as shown in figure 2. Surface preparation of the steel is very important as the adhesion strength of the coating is reliant on the mechanical bond achieved between the steel and the coating. For PVD, surfaces must be free of rust, oil, hardening salts, grinding burns, burrs and free from polishing mediums. It has been proposed that the PVD coating is most effective if the steel surface roughness is less than the coating thickness.

Although PVD is considered as a "low" temperature process, significant changes can occur in the base material during the coating process that negatively affects the performance of the coating - directly or indirectly. In brief, the initial heat treatment temper (or double tempers in many cases) should be performed at least 25°C above the PVD coating temperature otherwise significant thermally induced material movement can occur in the material during coating. Should material structures transform during coating - or even during the manufacturing

Rough machine » Stress relieve » Semi-finish machine » Harden » Finish grind » Polish » **COAT**

Figure 2 : *Basic recommended pre-coating procedures. Each coating may also require additional steps as indicated in the text.*

operation - the dimensional changes might close up tolerances and the coating may pre-maturely spall. In essence, dimensional movement is not desirable in any case.
The tool steel used must also not soften during the PVD coating process. Large hardness drops are observed for low alloy steel while with high alloy steels such as high speed steels, virtually no drop is observed [1]. Cobalt containing high speed steels are extremely effective in resisting softening. As also will be explained further, a softer base metal will lead to poor performance of the coating.
The PVD coating is generally recommended if metal pickup and galling are present.

CVD Coating

The CVD coating is a high temperature process, usually performed at ± 1000°C in specialized equipment. The most extensively used CVD coating is the dull gray titanium carbide (TiC), although TiCN (violet colour), TiAlN (anthracite) or a combination of coatings can also be deposited. The CVD coating in some cases has better adhesion strength over PVD as carbon atoms required for the coating carbide formation are partly supplied by the tool steel, thereby improving the bond strength. CVD is recommended if abrasive wear is present [4], however, the coating has not found much favour in the press tool market - the PVD coating being preferred.
The pre-process procedures for CVD are similar to PVD (figure 2), except that a further heat treatment step is required after coating. This is due to the CVD coating equipment not being able to achieve the required cooling rate to effectively harden the steel. Vacuum heat treating has to be employed to re-harden the steel otherwise the coating may evaporate off. Unless strict control is exercised, CVD is only recommended for tools and dies requiring relatively loose tolerances (± 0.03 mm).
CVD is effective in combatting wear, metal pickup and galling [4,5].

TD Coating

The TD coating processes may also deposit various carbides, however vanadium carbide is predominantly used. The TD coating has superior peeling strength compared to competing processes due to the fact that the substrate material supplies the necessary carbon atoms to form the ultra-hard vanadium carbide (VC) ceramic on the surface. The coating process is normally performed at the hardening temperature of tool steels (950°C~1100°C), and the material is coated and hardened during the entire process. The silver coloured coating performs best if the steel is polished to 1µm or less (i.e. mirror finish) prior to coating. Due to the extreme hardness, high abrasion resistance is obtained, and it has also found that the vanadium carbide has very low reactivity thereby preventing metal pickup and galling.
The pre-coating procedure for TD is similar to the PVD and CVD processes (figure 2). For TD it is very important to know the pre-coating heat treatment cycle. As the coating process a hot process, the heat treatment cycle is repeated during coating process to arrive at the same pre-coated metal microstructure and thus similar dimensions. The pre-coating grinding dimensions is very important and it should be verified with the coater prior to coating. As the processes is a hot process, there is also certain risk of distortion with some tooling and tool steels.
Good to extremely good performance is obtained and some local companies have experienced more than 50 times increase in die life, in the correct application. In the USA, for example, the TD coating is used by virtually all the catalytic stainless steel shell producers as its performance is unparalleled.
The performance of the coating can further be improved on (if necessary) by a post-coating heat treatment operation. The heat treatment once again mimics the original heat treatment cycle and this is done to improve the tool steel support (i.e. hardness) for the coating. The reason for this is that it has been found that insufficient hardness of the steel below the coating (due to the consumption of carbon from the steel by the coating in the case of CVD and TD, or from overtempering in the case of PVD), can lead to plastic deformation and subsurface cracking of the tool steel during operation [1]. This, in turn, leads to a premature degradation of the coating. The post-hardening cycle homogenizes the carbon and thus hardness (for TD and CVD), and increases the support for the coating.

Other Factors

Other factors to consider when specifying a coating is as follows :

- the coating adds to the component dimensions - up to 10 µm - and final dimensions may have to be adjusted accordingly.

- the selection of the correct tool steel and its heat treatment is very important to optimize the performance of the coating. Correct mechanical properties of the **tool steel** ultimately determines the performance of any coating.
- ideally, dies should be tried out prior to coating i.e. several components should be produced and the die examined for high spots or other anomalies. Regardless of the type of coating, if concentrated loads are experienced, the effectiveness of the coating will be reduced.

Summary

Only a relatively few high performance coatings are available for stainless steel component manufacturing processes. Some new coatings are underdevelopment however they have yet to be proven effective. However, the coatings mentioned have proved effective in sustained delivery of a quality component.

Although the applications of the coatings do overlap, each of the them have their particular niche in which they perform exceptionally well. However, the coating will only perform well if all the elements that make up a successful tool is correctly applied. An improperly prepared coated die may even deliver a worse product than its uncoated counterpart and it is therefore recommended to discuss the particular requirements with the particular coater in order to make the correct final tooling decision.

References

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