THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

HARD COATINGS FOR TOOL STEELS

by

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1. INTRODUCTON

All SRAMA members use tool steels. Generally tool steels are used for forming and cropping operations on wire and forming and blanking operations on strip. Traditionally the tool steels have been used in their as-ground condition. Some use of electroless nickel and hard chrome finishes have been tried in the past in order to reduce wear, but no member reported current usage of these processes. New processes have become commercially available within the last three years and each is claimed to reduce tool steel wear in forming and blanking operations.

These new processes can be broadly divided into three categories:-

1. Physical or Plasma Phase Vapour Deposition (PVD)
2. Chemical Phase Vapour Deposition (CVD)
3. Ion Implantation

Each process claims to improve tool life by two to ten times depending on the application.

PVD and CVD were developed primarily for improving the performance of cutting tools and both involve the deposition of titanium nitride or some similar hard, chemically inert layer. Ion implantation was developed primarily for semi-conductor production and involves the impregnation of surface layers with another element (generally nitrogen).

A survey of the above processes was made, and the applicability of each to the spring industry was considered, both for punch and die and automatic coiling operations. As a consequence of this survey, several in-service trials were set up. The results of the survey and trials are reported here.

2. SURVEY OF METHODS TO REDUCE TOOL WEAR

1. Background

Tools used for making springs do not last for ever. They wear out gradually by processes of chipping, yielding or abrasive wear. Chipping occurs when the tool material used is too hard, or insufficiently tough. Yielding occurs when the tool material is too soft. Often the choice of tool material hardness is a delicate balance between these two extremes. Tools that fail by chipping or yielding will not have reduced wear if a surface treatment process is applied. Optimising hardness and tool steel grade selection are beyond the scope of this report but will be mentioned later.

Tools that have the optimum hardness and toughness, and that fail gradually by abrasive wear or erosion, may show considerable life improvement if surface treatments are applied to the tool. The surface treatment must cost less than the time loss and costs involved in tool regrinds, if the surface treatment is to be an effective process that has value to the spring industry.

2. Processes Considered

2.1.a Hard Chrome and Electroless Nickel

These processes have been available for many years and are primarily designed to reduce wear in components made from carbon and alloy steels. The hardness of these coatings is not considerably greater than that of tool steels (see table 1) and the improvements in wear resistance possible are insufficient to be worthwhile, when applied to tool steels.

2.1.b CVD Titanium Nitride

Chemical Vapour Deposition (CVD) is used for applying wear resistant surface coatings at a temperature of about 1020-1080^{o}C. It produces a titanium carbo-nitride layer of between 2 and 8 m thick. Tools have to be separately hardened and tempered preferably in a vacuum furnace, after treatment.

The process is mainly used on cutting tools, often of substantial section, notably for drills and taps. Distortion of delicate tools is a problem as is the requirement to heat treat after applying the titanium carbo-nitride coating. The adhesion of the coating is good and relatively thick coatings can be built up economically. Also titanium carbo-nitride is a little harder than titanium nitride.

It is commercially available from Edgar Allen and PED (a GKN firm).

2.1.c PVD Titanium Nitride

Plasma or Physical vapour deposition is a process in which coatings are applied in a vacuum at temperatures between 200 and 550°C. The generally used coating is a 2 m layer of titanium nitride. In CVD there is a chemical reaction between the tool and the applied coating leading to a chemical bond. In PVD there is no such chemical reaction. The coating is applied by producing a plasma of liquid titanium particles and physically spinning the tools within this plasma. The deposition is encouraged by applied electrical fields or sputtering mechanisms. Nitrogen is introduced into the vacuum chamber in order to produce titanium nitride physical vapour deposition.

Again the main commercial application for PVD coating has been on cutting tools, notably drills, mills and gear hobbing cutters. Distortion of tools during the process is not a problem and the very small thickness of the PVD layer can often be accomodated without modification of tools.

The process is commercially available in the U.K. from

1. Multi-Arc (Europe) Ltd and JJ Castings Ltd (using Multi-Arc plant)
2. Torvac and Holt Bros. (using Tecvac plant)
3. Dowty Electronics
4. TI Abar
5. Inco Selective Services Ltd

2.1.d Ion Implantation

Ion implantation involves the bombardment of tools with ions of selected elements, usually nitrogen, under conditions of hard vacuum. This bombardment by highly accelerated ions causes a diffusion of the ions into the surface layers of the tool steel. The implantation causes a temperature rise in the tool and this temperature rise limits the speed and efficiency of the process. No dimensional changes occur as a result of the process, but considerable compressive stresses are introduced into the surface layer of the tools.

The main commercial application for this process is for manufacture of semi-conductors. It is not suitable for cutting tool applications in which tool temperatures over 400°C are possible.

The process is commercially available in the U.K. from

1. Tech-Ni Plant Ltd
2. Ion Implantation Ltd (using AERE Harwell equipment)
3. Tecvac

2.2 What Materials can be treated by these processes?

Advantages are gained from CVD, PVD and ion implantation when applied to chromium containing tool steels and tungsten carbide tools. The chromium content helps the adhesion of PVD coatings, but is less important for CVD coatings. The chromium containing tool steels used most frequently by the spring industry are:-

D2 type	high carbon 12% chromium steel
M2 type	6-5-2 high speed tool steel

01 type tool steels do not contain chromium but CVD methods can be used to advantage it is claimed.

2.3 How long do the processes take and what tools can be treated?

The cycle time for CVD, PVD plating is a few hours and for ion implantation several hours in the vacuum chamber generally. However the cleanness of tools is vital prior to the above processes. All firms who offer these processes have elaborate systems for degreasing, ultrasonic cleaning, washing and drying of tools. They will refuse to treat excessively dirty tools or those exhibiting temper oxide.

The usual turnround time quoted for return of tools is seven days, but SRAMA experience is that seven to ten working days is the best performance that can be offered reliably. Tools sent for PVD or ion implantation should be in the 'ready for use' condition. Brazed tools can be treated by some PVD processes, but any mechanical joints that cannot be fully dried prior to treatment are likely to 'bleed' when subjected to the vacuum and plating or ion implantation in this region will be ineffective. The tool steel grade and tempering temperture used need to be stated.

2.4 How much do these processes cost?

The cost of CVD titanium nitride plating is difficult to state clearly since the tool needs to be hardened after plating, but the cost is generally between that of PVD and ion implantation.

PVD titanium nitride plating is a relatively low cost process. A few small punches for instance will incur the usual minimum charge of £30. A die with a surface area of 15,000 mm^2 say with its separate punches might cost between £80 and £100.

Ion implantation is more expensive due to the harder vacuum required by the process. For tools of a surface area of 15,000 mm^2 the cost of treatment is likely to be about £250 to £350.

3. POSSIBLE APPLICATIONS WITHIN THE SPRING INDUSTRY

A survey was undertaken by telephone to establish which tools, used within the spring industry, suffered progressive wear. It was apparent that all forming, cutting and blanking tools were deemed to be within this category, but springmakers did not really know what type of wear was responsible for their need to regrind and/or replace their tools. Hence worn tools were asked for, via the Newsletter, so that SRAMA could assess the applicability of coatings to reduce the wear of these tools. When such tools were received, questions were asked about the cost of the tool, the cost and time involved with regrinding and replacing the tool, and about the cost of lost production while attending to the tool.

Some important conclusions were drawn from this survey. Firstly, most tools used by springmakers are low cost, easy and cheap to regrind and the time involved with changing some tools was insignificant. Secondly the wear that took place on many forming tools could easily be accomodated by simple adjustments of their position. Finally, orders that were sufficiently large to necessitate any tooling adjustments during the production run were unusual.

When this background was compared with the claims made by suppliers of hard coatings for tool steels the criteria for possible applications in the spring industry were believed to be:-

1. Large quantity orders and tool wear of the correct type occuring
2. Relatively high cost tools (e.g. made by spark erosion)
3. High cost regrinds/tool replacements
4. High cost of down time on springmaking equipment

Criteria 1 together with 2 or 3 or 4 were considered necessary before the cost of the hard coating could be offset against financial savings in spring production.

One other possibility for successful application of hard coatings that was not explored adequately within this limited programme of work was the applications for which a springmaker had resorted to the the use of carbide tooling. Carbide tooling can involve high costs whereas the toolsteels purchased by springmakers are generally a small part of the total cost of making a tool, especially when the tool is repeatedly reground. For applications where carbide tooling had been used due to excessive wear, it may be that a plated tool steel may perform equally well.

4. IN SERVICE TRIALS

Trials using coated tools were set up following SRAMA's offer of free trials, advertised in its Newsletter. Approximately ten members made contact with the author requesting information about the benefits they might accrue from the aforementioned coatings.

The original plan for this project envisaged that two applications only within the spring industry would be considered. These were tools for punch and die sets and tools used in automatic coiling machines. In practice the requests for information covered the above two applications together with tools used for machining springs. No trials were set up by SRAMA for this last application, but some advice was given and some feedback of results is included in this report. All trials set up used PVD titanium nitride coating on tools.

4.1 Punch and Die Sets

Two members reported results of trials prior to this project. One trial had been successful and this success was built upon further, the other trial had been unsuccessful, and the reasons for the lack of success became clear during the course of the trials set up by SRAMA. Trials at two other member firms were set up.

Each participant reported initially that punch and die wear was not a significant problem when punching annealed carbon steels and copper alloys. However tool life when punching austenitic stainless spring steel, nickel alloys and pre-hardened and tempered carbon steel was always at least 80% less than that experienced when punching the softer materials.

Trial 1

The component being produced was blanked from .080" thick CS70 annealed strip. The shape of the components was not intricate and several were produced with each blow of the punch and die set. The punch and die set consisted of one die and several small punches all made from high carbon high chromium (D2 type) tool steel. No allowance was made for the thickness of the PVD plating, but this very thick component was selected for the trial in order that no extra machining of either punch or die was required. It would be expected that no allowance need be taken for the PVD plating thickness for any component thicker than .040", and it may be that no allowance is necessary for much thinner components.

PVD titanium nitride plating was applied to both punches and dies and the temperature was controlled below 270° during plating. Prior to plating the reground part used tools had been thoroughly cleaned.

No problems were encountered when re-assembling the punch and die set. An improvement tool life from between 100 and 150 thousand blows to over 300 thousand blows was reported when comparing uncoated tool life with coated tool life. The estimated cost saving regrinding the tool was £70, which roughly balanced the cost of applying the plating. However the smallest punches were worn to a greatr depth (i.e. .160") than normal after plating. The reason for this greater depth of wear was not ascertained.

Trial 2

This trial involved the stamping of flat components from .45mm thick pre-hardened and tempered steel strip. The tools were made from high carbon, high chromium D6 type tool steel. No allowance was made for the thickness of the plating.

When these tools were returned after plating it was observed that the assembly fit of the tools was tight. The tool life recorded with the plated tools was 6 to 10 thousand blows before regrind, compared with 25 thousand blows before regrind, for unplated tools. The edge of the punches appeared to be collapsing on the plated tools.

It is suspected that the reduced tool life recorded in this trial will be partially attributable to the changed punch and die clearance due to the plating.

Some components produced immediately prior to taking out the tools for regrind were supplied to SRAMA. The reason for deciding to regrind tools in this instance was not the build up of fash but the deterioration in surface roughness of the component edge. This is usually measured subjectively, but may be measured using a Talysurf. The average surface roughness of components made using the plated tools was checked and found to be worse than that for components made prior to plating the tools.

Trial 3

Complex shaped components made from .025mm thick annealed CS70 carbon steel were the subject of this trial. The punch and die both made from D6 type tool steel were PVD titanium nitride plated. No allownce was made for the plating thickness.

Prior to plating the tools 1.8 to 2 million components were made between each regrind of the tool. No improvement or deterioration in this output between regrinds was observed as a result of the plating of the tools. However the reason for taking out the plated tools after 2 million components had been made is not known. Nor is it known if the tool was worn. This trial was set up to run hard rolled stainless, but no orders came to hand after the plating was done so the tools were used on carbon steel.

Trial 4

Piercing punches designed to produce 0.25mm slots through .040mm thick phosphor bronze PB103 were the subject of this trial. The phosphor bronze had a hardness of 235 VPN.

Initially the punches were made from D3 tool steel and were spark eroded to a size to allow for a PVD titanium nitride layer. Only the punches were plated, the die was not considered in this trial. The plated punches improved life from a few hundred blows to 330,000 blows. All unplated punches broke and were not serviceable. One of the plated punches broke after 330,000 blows but the others in the tool were successfully ground and will be re-used.

As a result of this trial, in which the component had been made successfully in phosphor bronze for the first time, further punches were plated, but the substrate material used this time was ASP23 (Uddeholm powder metallurgy tool steel). The ASP23 was in a softer than usual condition i.e. 60/62 HRC. A run of 60,000 blows was completed with no noticeable deterioration of the tool. The tool will be re-used without grinding.

A further trial on the same component was tried using special tungsten carbide tools, without plating. This ran for 175,000 blows before a punch broke.

No clear conclusion has emerged from these trials as yet, but it is quite likely that the cheapest option for this difficult component may well be to PVD titanium nitride plate D3 punches.

Trial 5

PVD titanium nitride punches were tried on a half hard CS4 Mild steel part. Again the punches were plated and the die was not. The tool steel used for these punches was A2. Prior to plating the interval between regrinds was 100,000 blows. The interval after plating was 200,000 blows. The life after regrind has not been evaluated at the time of writing this report, but an improvement over 100,000 blows is expected.

4.2 Automatic Spring Coiling Machines

Only one trial was actually carried out on automatics. This was due in part to some applications that were submitted to SRAMA being examples of wear that PVD plating could not help. It was also due, in part, to tools being prepared for PVD plating and they were then used because an emergency cropped up, that did not allow for the delay incurred by sending the tools away.

Trial 6

In this trial the wire guides of a Simplex automatic were PVD titanium nitride plated. The springs that were coiled on this machine were generally of small index and the two grades of wire used were both pre-hardened and tempered BS 2803 wires - i.e. carbon and silicon chrome.

The wear of the wire guide was not reduced when running the silicon chrome wire. It appeared that the coating was rubbed through very quickly. A small improvement in wire guide wear was observed when running the carbon wire, but the improvement did not yield financial savings that could justify the cost of the PVD plating.

Trial 7

In this trial a number of coiling points were submitted for PVD plating. All were part used and reground tools except one large new angular coiling point, which was not made from a chrome containing tool steel. The tools were rejected for PVD plating due to the ingrained dirt and grease on the tools that could not be removed. The tools for PVD plating must have freshly ground surfaces and must be capable of being cleaned to a very high standard or the PVD plating will not adhere.

4.3 Other Applications

Two reports of experience with hard coatings were reported to SRAMA outside the scope of these trials, but the results are informative and so are included here.

Trial 8

A wear plate against which hard drawn CS70 wire was continually rubbing was a problem. Its position needed to be adjusted as the groove wore in it. This plate was made from 01 tool steel after harder grades were found to shatter occasionally. CVD plating to .08mm thick was tried and wear was reduced considerably. Now all such plates in this firm are CVD plated. Distortion of the very simple shape of this wear plate could easily be accomodated in this application.

Trial 9

Hardened spring clips had to be tapped prior to plating. The wear on the taps was considerable and so CVD plating was tried. A reduction in tap life was observed after CVD plating due to chipping of the titanium carbonitride layer on the tap.

5. DISCUSSION

The results from the in-service trials gave both encouraging and discouraging results. However one pattern did emerge from the multifarious trials and that was that PVD titanium nitride is more effective in reducing tool wear when it is used on tools that cut or form softer spring materials. All trials in which pre-hardened and tempered materials were being formed or punched showed no improvement in tool life after PVD plating. It is assumed that this discouraging result is attributable to the fact that the material being formed is only a little softer than the tool steel substrate beneath the PVD plating (see table 1).

On the other hand nearly all applications investigated in which softer spring materials were being formed showed some improvement in tool life. This observation serves to impose a further limitation on the criteria for possible spring applications detailed earlier in section 3 of this report. Tentatively, it may be suggested that success with PVD plating is less likely if the material being formed has a hardness in excess of 500Hv.

The scenario described in trial 3 clearly illustrates the pitfalls and shortcomings likely to be encountered when setting up in-service trials. The reason for stopping presswork in order that tools may be reground is generally the gradual appearance of fash on components due to wear of the tooling. The judgement of when a fash is unacceptable is a subjective one and depends critically upon operator skill. If the component is run too long irreparable damage may be done to the tooling. This subjective judgement leaves the results of these in-service trials open to a wide range of interpretations, and casts doubt upon some of the claims made by suppliers of PVD plating. Nonetheless SRAMA are not aware of a better way of evaluating new technology such as this for the benefits of all its members.

In all the trials set up the efficiency of the PVD titanium nitride plating was assumed to be good. However it is possible for this new process to be inefficient and the result is a plating that adheres poorly to the substrate tool steel. There is a need for a quality control check to ensure that the process has been carried out correctly. Suppliers of the processes are working on this problem, but an independent inspection authority would be preferable, once a quick and easy test is established.

During the course of discussions about PVD titanium nitride plating at one springmakers, the tempering history of the tool steels they used was investigated. The firm supplying the PVD plating needed to know the tool steel tempering temperature in order to ensure that this temperature was not exceeded during the PVD process. However the investigation revealed that D3 tool steel had been single tempered after hardening and that ASP23 (an Uddeholm powder metallurgy grade) was tempered twice. D3 should be tempered twice and ASP23 three times for optimum toughness. If tools are incorrectly heat treated there may be a tendency to over specify tool steel grade, and many tooling problems may stem from this fundamental reason. The tool steel raw material represents a relatively small cost in the production of a tool, so care in specifying the heat treatment makes sense and may help improve tool life without resorting to hard coatings.

6. CONCLUSIONS

Physical phase vapour deposition of titanium nitride will show economic benefits to applications in the spring industry in which the following criteria apply:-

1. Very large quantity orders, in which tools wear by erosive or abrasive processes neccessitating adjustments/replacements.
2. The material being processed has a hardness of less than 500Hv.
3. The tools used are relatively high cost.
4. The cost of regrinds/tool replacements is relatively high.
5. The cost of down time on the springmaking equipment is relatively high.

The above criteria are much more likely to be found on a punch and die set than on an automatic coiling machine.

7. RECOMMENDATION

The processes for hard coatings on tool steels are becoming more widely available and use of these new technologies is increasing rapidly. The possible advantages to springmakers should be continually monitored.

Table of hardness values

Material	Hardness/Hv
Cemented Carbides	1300/1800
Hard Chrome	900/1100
D2/M2/ASP23 tool steels	720/800 (62/64 HRC)
PVD Titanium nitride	2000/3000
Diamond	10,000
Pre-hardened and tempered wire or strip	500/600

Table 1