Hard Coatings on Contaminated Surfaces — A Case Study

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Physical Vapor Deposited (PVD) coatings such as TiN (titanium nitride) have been a boon for cutting tool manufacturers. They reduce wear and, therefore, extend tool life, which in turn reduces production costs. But PVD coatings are expensive, and when they fail, they cost both time and money, and the causes of the failure are not always readily apparent.

Although the present case study deals with taps, its conclusions are equally valid for any ground metallic surface, such as those found in tool and die cutting and forming and medical instrument, firearm, and gear cutting tool manufacturing, or any other process where grinding is one of the manufacturing operations.

Bad Taps

A customer turned to us with the request to analyze a batch of PVD titanium nitride (TiN) coated taps. Although the coating looked perfect, with a shiny, even, deep gold hue, the taps failed prematurely: There was immediate adhesion and edge buildup.

In the beginning, we suspected adhesive failure due to inadequate cleaning prior to TiN deposition. Subsequent analysis of the failed tools showed that the reasons were more subtle.

Taps typically contain three different surfaces: Their shanks are ground on a centerless grinder, often by a third party; their flutes are either milled or ground by a relatively coarse grinding wheel, and the threads are usually ground by a finer wheel which contains the thread profile.

As a rule, the coarsest surface is that of the flute. Therefore, insufficient cleaning would cause coating failure predominantly on the flutes. However, in this case, scratch tests under the microscope revealed stable coating, with good adhesion on both the flutes and shanks, but consistently high failure rate on the flanks.

PVD processes are inherently delocalized: They do not produce large differences in the coating quality of adjacent areas of identically prepared surfaces. The coating differences on flutes and flanks could not be caused by the PVD process, and the good coating quality on shanks and flutes was an indication of correct technology.

Therefore, we concentrated on the flanks. Secondary ion mass spectrometry, auger electron spectroscopy and electron induced X-ray spectroscopy revealed contaminated para-surface regions on the flanks. Moreover, the comparison of surface chemistries of the flanks and the grinding wheel indicated that most of the contamination originated from the grinding wheel.

Grinding Wheel the Culprit

How is material transferred from a grinding wheel to the workpiece? What is the mechanism of impregnation of contaminants into the surface? These questions could be answered by considering the grinding mechanism.

A grinding wheel consists of a relatively soft, often porous matrix with hard abrasive particles embedded and anchored in it. In a new or freshly dressed wheel,

Surface Preparation for PVD Hard Coatings

Surface cleanliness, a prerequisite for high coating quality, can be achieved by observing the following guidelines:

- Dress grinding wheels three or four times more frequently than for uncoated parts. Avoid "spark-out," which causes cold working of impurities into surfaces. Make sure there are no burrs on edges.
- Avoid rubberized or resinoid buffing wheels or diamond polish.
- Do not sand- or bead-blast or vapor-hone surfaces.
- Use good quality silicon carbide wet-and-dry paper for manual polishing. Start with a coarse grit and proceed in small steps with finer and finer paper until the desired finish is achieved. Use plenty of water, changing water and rinsing between steps. Change paper frequently and apply only light pressure to minimize rubbing and maximize cutting.
- Do not use peel or dip coat and/or hydrocarbon rust preventives, such as WD-40.
- Do not use chemical scale or rust removers/preventives.
- Remove screws, clean tools of shop soil in a mixture of one part machine oil (any kind will do) and 16 parts mineral spirit. Cleanliness of crevices and coolant ducts is especially important.
- Use cadmium-free braze for brazed tools; make sure there are no crevices and pinholes in the brazed joint.
- Do not attempt to coat black-oxided or electroplated surfaces.
- To ship, wrap tightly in newspaper.

sharp abrasive particles protrude from the surface. During grinding, weakly bound particles are dislodged from the wheel matrix and lost. The remainder cuts the workpiece material and wears continuously; the average edge radius of the abrasive particles increases with time, causing an increase in the cutting forces and leading to plastic deformation of the workpiece surface.

With increasing forces on individual particles, an ever-increasing number are lost, and fewer particles with larger and larger edge radii come in contact with the workpiece. Consequently, the material removal rate decreases and the generated heat increases. This process is exacerbated by "loading" of the wheel with debris from its own surface and the workpiece. Eventually the material removal ceases, and the wheel only rubs the surface, causing intense heating and melting or "glazing."

During grinding, foreign matter from the grinding wheel and the coolant is deposited onto the workpiece. Furthermore, freshly exposed metallic surfaces are chemically reactive and quickly oxidize and/or react with constituents of the coolant. However, because of the high removal rate of a freshly dressed grinding wheel, these impurities are effectively removed, and the surface remains clean.

As the wheel wears and the removal rate decreases, a residual impurity layer is formed on the surface and cold-worked into the material, thus creating a mechanically burnished, chemically impure parasurface region. The impurity concentration is further enhanced by increased diffusional mass transport caused by the heat generated by the worn wheel.

With the increasing non-metallic impurity concentration, the coating adhesion monotonically decreases up to the point of spontaneous coating delamination from the surfaces. There can be noticeable deterioration well before the appearance of visible signs of surface loading, which makes it difficult to define the proper wheel dressing procedures and frequency.

From the preceding description, it is clear that incorrect grinding can cause coating failures. Well dressed, relatively soft, open wheels should be used for grinding surfaces intended for PVD coatings. Optimum wheel composition, grade and dressing conditions for a particular application are usually suggested by the suppliers or found by trial and error. A good rule of thumb is that the frequency of dressing of grinding wheels should be some three to four times higher for taps that are to be coated than for those remaining uncoated. ○

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