

PHYSICAL VAPOR DEPOSITION OF THIN FILM HARD WEAR RESISTANT COATINGS

Physical vapor deposition (PVD) covers a broad class of vacuum coating processes in which material is physically removed from a source by evaporation or sputtering, transported through a vacuum or partial vacuum by the energy of the vapor particles, and condensed as a film on the surfaces of appropriately placed parts or substrates. Chemical compounds are deposited by either using a similar source material, or by introducing a reactive gas (nitrogen, oxygen, or simple hydrocarbons) containing the desired reactants, which react with metal(s) from the PVD source.

A broad family of PVD processes have evolved over the last twenty years. They are known by various phrases or acronyms that are sometimes more confusing than descriptive. Most are named for the physical vapor source; for example, diode or triode sputtering, planar or cylindrical magnetron sputtering, direct current (DC) or radio frequency (RF) sputtering, electron beam evaporation, activated reactive evaporation, and arc evaporation. Despite any name confusion, all PVD processes can be separated into three distinct phases:

1. Emission from a vapor source.
2. Vapor transport in vacuum.
3. Condensation on substrates to be coated.

Historically, PVD processes have been relatively expensive as the result of slow deposition rates, expensive vacuum equipment, and throughput limitations. In recent years, the use of PVD methods has expanded at an extremely rapid rate owing to reduced costs and, more importantly, because of increased demand for high-performance materials and coatings that cannot be produced by other methods.

PVD PROCESS CONSIDERATIONS Although PVD methods typically require more expensive equipment, more parts preparation, more system maintenance, and greater processing times than many alternate processes, PVD is a viable coating process for hard coatings. In some instances, PVD is the only method capable of depositing a coating of the desired material. The overall cost of PVD can often be less than other coating methods when all factors are taken into account. The primary considerations that must be evaluated before selecting a PVD process include desired end result, substrate properties, cleaning and preparation, fixturing, temperature, and coating rates. When alternative means of achieving the end result are available, total costs must be compared among the alternatives; total cost would include equipment cost and operating environment.

Substrates

The easiest substrates to coat are those that are electrically conductive and remain stable (minimum outgassing or decomposition of bulk material) at elevated temperatures. The level of difficulty and the number of process constraints increase when progressing from metal to glass to plastic substrates.

With metal substrates, certain materials, surface conditions, and assembling techniques must be avoided to achieve good adhesion and film properties. For example, cadmium and zinc alloys create problems during coating if the temperature exceeds 390 F (200 C) because of their high vapor pressures. Porous metals such as low-grade castings are generally difficult to coat because oils and contaminants remain entrapped in the pores. Burrs must be removed from the parts before coating to prevent exposure of uncoated metal when they are broken off later. Other surface conditions that reduce film adhesion are surface oxides, grinding burns, imbedded polishing compounds, and rust-preventive films. Parts that have been brazed or press fit together are often difficult to coat by PVD because of contaminants entrapped between the parts. Although some materials and assembly methods are undesirable for PVD coatings, many of the problems previously described can be overcome by thorough cleaning and operating parameter adjustments.

PVD FILM EVALUATION

In a production environment, films are typically evaluated for visual defects, thickness,

and adhesion. Visual defects such as bare spots, small voids, incorporated flakes, or debris can be observed with a stereo microscope having a magnification of 10 to 100 times.

Film thickness is generally measured by one of the following methods:

- Polished metallurgical microsections are used to microscopically observe the coating thickness on various part surfaces. This method is the most direct way to determine thickness uniformity.
- Beta (high-energy electron) backscatter instruments are used to measure the film thickness nondestructively. This is an indirect method that requires calibration with a known standard; substantial errors can be made in measuring the film thickness on curved surfaces if care is not exercised.
- A ball-crater instrument can be used to polish through the surface of a coating. The relationship between the diameter of the polishing ball, the maximum diameter that shows the effects of polishing, and the diameter of the substrate area that is exposed by polishing is used to calculate the thickness. Coatings that are up to 120 m-in. (3Mm) thick can be measured with an accuracy of ± 4 m-in. (± 0.1 Mm) without difficulty on relatively smooth, flat or cylindrical surfaces.
- X-ray fluorescence or energy-dispersive X-ray analysis in a scanning electron microscope can be used to measure film thickness.

The adhesion between coating and substrate is difficult to measure directly for highly adherent films; pull tests capable of measuring yield strengths that are typical of metals and PVD hard coatings on metals have not been developed. A commonly used indirect test is the manual stone abrasion test (SAT). In this test, a fine sharpening stone is rubbed back and forth across the coated surface, allowing the stone particles to make grooves in the surface by nonelastic deformation. The film is then inspected under a microscope to obtain adhesion information.