Considerations in the Selection of

COATINGS

Both technical and economic issues should be considered in the selection of the best coating for a given application.

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The selection of a surface coating or other surface modification or treatment (hereinafter simply called coatings) should be based on the total system. The intended function of the surface must be known, including factors such as its expected life, the service environment, the substrate (component alloy, heat treated condition, etc.), and any mating surface characteristics, if applicable. Then both the technical and economic issues regarding the coating itself must be analyzed, based on the life cycle cost and benefits of the coating, not just the direct procurement cost, as is so often done.

This article discusses the classification of coatings, technical challenges in selection, part and substrate constraints, environmental considerations, and economic issues.

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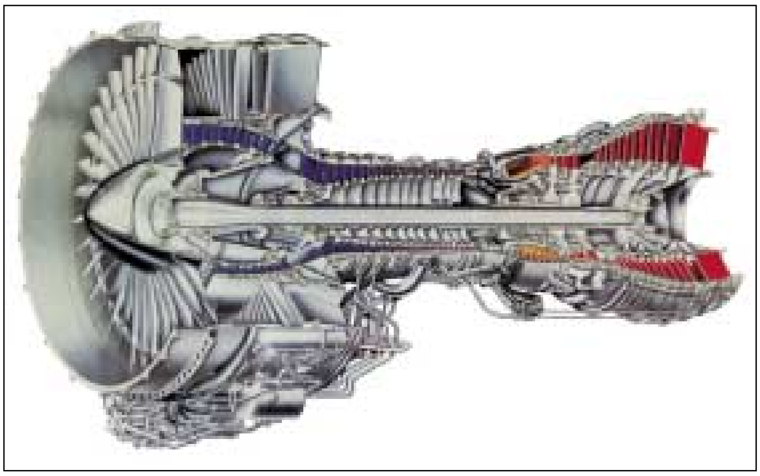

Complex shapes such as turbine blades are difficult to coat uniformly with line-of-sight or nearly line-of-sight processes. Gas turbine blades, both compressor and turbine section blades and vanes, are coated with a number of coatings using both thermal spray and EBPVD. Image courtesy Pratt & Whitney.

Classification of surface treatments

Coatings may be classified in many ways. A method based on how the material is applied to the surface or how the surface is modified leads to the following classifications: atomistic deposition, particulate deposition, bulk coatings, and surface modifications. Coatings that fall within these classifications are shown in Table 1.

Table 1 — Classes of coatings and claddings

Atomistic deposition	**Particulate deposition**	**Bulk Coatings**	**Surface modification**
Electrolytic deposition • Electroplating • Autocatalytic • Fused salt • Chemical displacement	Thermal spray • Flame spray • Electric wire arc spray • Plasma spray • High-velocity oxy-fuel spray • Detonation gun deposition • Cold spray	Wetting process • Painting • Dip coating	Chemical conversion • Electrolytic • Anodization • Fused salt
Chemical vapor deposition • Chemical vapor deposition • Spray pyrolysis	Impact plating	Electrostatic spraying • Printing • Spin coating • Liquid	Chemical • Thermal vapor • Plasma vapor
Vacuum deposition • Vacuum evaporation • Ion beam • Molecular beam epitaxy	Fusion coatings • Thick film ink • Enameling • Electrophoresis • Spray & fuse / sprayfuse thermal spray	Cladding • Explosive • Roll bonding	Mechanical • Shot peening
Plasma deposition • Sputter deposition • Activated reactive evaporation • Plasma polymerization • Ion plating		Overlay • Laser cladding • Weld overlay	Thermal surface enhancement • Diffusion from bulk
		Self-propagating high-temperature synthesis	Sputtering
			Ion implantation

Frequently, a coating of a given composition can be produced by two or more of the methods or processes listed in Table 1; however, the microstructures and properties generated will probably be significantly different. Moreover, the microstructure and properties of a given coating composition produced by a single process may also vary significantly, depending on the process deposition parameters. Thus, coating selection and specification is not a simple exercise!

Technical issues in coating selection

At least three major areas of technical issues are involved in the selection of a coating: the function or purpose of the coating, part or component constraints, and environmental constraints. Some of the functions or purposes for which a coating or surface modification may be used are:

- Wear and / or corrosion resistance
- Thermal insulation or conduction
- Electrical insulation or conduction
- Electronic function
- Magnetic properties
- Optical properties
- Dimensional restoration

As an example, coatings frequently provide wear resistance. Table 2 shows the abrasive wear test results for several selected coatings of materials produced by various thermal spray processes, PVD cathodic arc deposition, and electroplating with a solid sintered material. Based only on this information, the Super D-Gun WC-Co-Cr or PVD ZrN coatings would appear to be the best choices, but other factors must also be considered.

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Table 3 compares properties of several coatings, including those listed in Table 2. Note that the ZrN PVD coating requires some elevation of the substrate temperature during deposition, thus eliminating it for substrates that cannot withstand this exposure without degradation of required properties. For example, the substrate could lose strength due to phase changes or annealing. The high temperature required for many CVD coatings can be a particularly difficult or impossible problem for many substrates.

Thickness of some coatings has significant limitations, as shown in Table 3. Furthermore, coating defects such as the interconnected porosity of most thermal spray coatings, or microcracks in some electroplated coatings, can present a problem in corrosive environments. These defects may or may not be overcome with sealants or undercoats.

Part and substrate constraints

Other part or substrate constraints must be considered in the selection of coatings. The size and shape of the part may be a major limitation. For example, a paper mill roll that is two meters in diameter and ten meters long will not fit inside most chambers required for PVD or CVD coatings. Conversely, very thin or small components may be distorted by either the heat of the process or residual stress in the coating.

Complex shapes such as turbine blades are difficult to coat uniformly with line-of-sight or nearly line-of-sight processes such as thermal spray. The interior cooling passages of turbine blades can be coated only with a non-line-of-sight process such as chemical vapor deposition.

In many cases, the coating must be confined to a specific area on the component. This means that the coating process must either be capable of precise control of the area covered, or masking is required. Any masking must, of course, be stable throughout the coating process, and must not degrade the structure of the adjacent coating due to shadowing, particle bounce, or some other event.

The effect of the coating on the performance of the part must be considered. For example, some electroplated and thermal spray coatings have been shown to significantly reduce the fatigue properties of many steel, titanium, and other alloys due to high residual stresses. These effects can be ameliorated to some extent by shot peening the part before coating. Or, they may be essentially prevented by selection of processes such as Super D-Gun or some HVOF technologies that yield coatings with compressive rather than tensile residual stresses.

As another example, a poor choice of coating may create a galvanic couple or provide sites for crevice or pitting corrosion that would seriously degrade the corrosion characteristics of a part in the service environment.

Conversely, the part may have an effect on the performance of the coating. Most obviously, the part must provide mechanical support so that the coating is not strained beyond its capability under the loads imposed on the surface of the coating (e.g., impact or wear loads), or as a result of strain on the substrate due to mechanical or thermal loading.

Environmental considerations

Environmental considerations in coating selec-

Table 2 — Abrasive wear of selected coatings

Material	Type	Wear rate, mm^3/1000 rev
WC-Co	Plasma spray	5.5
WC-Co-Cr	Detonation gun	1.6
	Super D-gun	1.2
	Super D-gun	0.6
ZrN	PVD cathodic arc	0.8
Cr	Electroplated	8.0
Carballoy 883	Sintered bulk	1.2

Table 3 — Comparative properties of selected coatings

Coating type	Application temp., °C	Thickness, microns	Density, %
Thermal spray	<150	25 to > 2500	80 to >98
CVD	Most >900	<1 to ~ 75	~ 100
PVD	<700	<1 to ~ 20	~ 100
Electro-plate	<80	<100	~ 100

tion relate to both the service environment and the production of the coatings. The service environment obviously affects the coating material selection. Will the coating be exposed to ambient air, high temperature air, or other fluids, fresh or salt water, or other chemicals? The coating not only must withstand this environment, but also must often protect the substrate from attack by the environment.

Another set of possible environmental constraints may result from the effluents generated by the coating or surface-modification process, substrate surface preparation, or finishing operations. Control, containment, and disposal of such effluents or waste can be not only technically challenging, but also costly in both capital and operational expenditures. The most prominent example is probably the control and disposal of Cr^{+6} in chromium plating, but other examples include containment of grit and dust in the preparation of surfaces for thermal spray, and grinding fluids and debris in the finishing of many coatings.

Economic issues in coating selection

Consideration of the economic issues in the selection of a coating should include at least the following: the total cost to produce a coated part, sourcing issues, the life of the coating and associated operating maintenance costs (incurred, deferred, or eliminated), and additional benefits of the coating. All of these must be included when comparing coatings for a given application. The total cost to produce a coated part includes at least the following cost components:

- Substrate cost. For example, can a less expensive alloy be used?
- Substrate preparation cost: machining, finishing, cleaning
- Coating cost: fixturing, masking, deposition, etc.
- Sealing
- Finishing
- Quality control

Obviously, each of these cost components must include all of the elements of associated costs. These include not only the direct consumable and labor costs, but also amortization of equipment, overhead, waste disposal, etc.

Not infrequently, a lower-cost substrate alloy would be suitable if the coating could be relied upon to provide wear resistance, corrosion resistance, or other properties. Therefore, the substrate cost should be included in the total cost comparison exercise, unless the substrate alloy is fixed for some other reason. Note, however, that the substrate alloy may be assumed to be fixed for invalid reasons.

The substrate preparation cost analysis should include all machining, finishing, and cleaning costs for each coating being considered. Differences may be significant based on the coating process. For example, an electroplated coating requires that the substrate be finished to a much lower roughness than a thermal spray coating, since the latter will be grit-blasted before coating. In at least one instance, the higher cost of finish machining a part before chrome plating, more than compensated for the somewhat higher direct coating cost of a detonation-gun tungsten-carbide-based coating, even without considering substantially superior wear resistance and longer life of the detonation-gun coating.

The coating cost should include not only the cost of deposition (consumables, labor, equipment amortization, etc.), but also fixturing and masking. The costs of sealing, if required, and finishing must, of course, include the cost of effluent control and waste disposal.

Finishing costs can vary drastically with the process. Appropriate finishing can often determine the success or failure of a coating application. Therefore, an attempt to save money with a cheaper finishing process may instead doom the application to failure, or lead to the choice of a less than optimum coating based on a misleading test evaluation.

Quality control is an essential element in producing coatings or surface modifications. The specific equipment and techniques will depend on the specific coating, process, and application. Somewhat greater costs incurred in quality control are usually more than compensated for in reduced rework, longer and more reproducible coating life, reduced cost of equipment failure and production down time, etc.

Sourcing issues

Sourcing issues in coating selection can be complex and are often influenced by other issues such as logistics, corporate finance policy, or strategic direction. Coatings can be produced internally or purchased as a service.

If produced internally, it is not sufficient to consider only the cost of equipment, consumables, and labor. Infrastructure costs should be calculated as well, including surface preparation and finishing, quality control, engineering support, and the training of personnel.

If purchased from a coating service, the logistics involved with having the coating applied by the service is a major consideration, as well as finding one or more well-qualified sources. An alternative may be to obtain a service source that will install a facility onsite or across-the-fence, thus

The Mustang GT convertible concept vehicle relies on a wide variety of coatings and surface treatments to enable high performance. Photo courtesy Ford Motor Co.

eliminating most of the logistics, infrastructure, and personnel problems.

Cost analysis

When analyzing costs, the total life cycle must be considered. These include the life of the coating, whether or not the part can be recoated (replacement or refurbishment costs), and the cost of downtime when the coated part must be removed from service and replaced (lost production and labor and other costs to replace).

Each coating offers its own set of potential benefits that should be included in any economic analysis. The first may be whether or not a coating is an enabling technology; is it critical to the performance of the process or part? A specific coating may enable a whole new process or product to replace the existing one, or enable a very substantial improvement on the existing one.

Whether enabling or not, a coating frequently improves the quality of the product. For example, most of the rolls in a steel sheet galvanizing or annealing line are coated, in part, to prevent the build-up of nodules of metal and oxide that would damage the sheet. Without these coatings, the sheet would be unsuitable for many applications such as car bodies and appliances. In other applications, coatings can also improve safety, reduce liability risk, and reduce warranty costs. ■

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