Using thermal-spray metal coating on carbon steel to prevent corrosion is a process that has been around for most of a century. Under its traditional and more familiar name of “metalizing,” thermal-spray coating has prevented corrosion on carbon steel lock gates, dam components and similar large marine-environment structures since the early 1900s.

Today, thermal-spray coating is applied by arc spray or flame spray; flame spray is the older, more traditional application method, and — in appearance — seems similar to brazing, although in fact, the thermal spray coating process and the protective film it produces are closer to a liquid-applied coating system. Arc-spray application of thermal-spray metal coatings was a shop-bound process until the 1990s, when portable arc-spray equipment was developed and introduced into field maintenance coating procedures.

For refining and petrochemical projects using thermal-spray coating, arc spray is preferred for large, relatively smooth surfaces such as tank roofs or exteriors of large process vessels (Fig. 1).

By Peter Bock, Advanced Polymerics, LLC

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Smaller and more intricate surfaces, such as small-diameter piping, valves and flanges, are done with flame spray. Where a project is large enough, both processes are used to benefit from the advantages of each.

Metal Types
A wide variety of metals can be used for thermal spray coating; the author has watched bronze thermal spray being applied to bronze statues whose surfaces had deteriorated from long-term environmental exposure in a polluted urban environment on the U.S. Gulf Coast. Thermal-spray zinc was originally touted as a competitor to hot-dip galvanizing, although the two processes are significantly different in application and in the resulting corrosion-resistant film they form.

Hot-dip galvanizing is most definitely a shop process, totally unsuitable for any sort of field or maintenance application. In times when environmental considerations were not as strict as they are today, a large-scale galvanizing facility, with huge open vats of strong acids or alkalis and an equally large vat of molten zinc at 700 F was perfectly acceptable; today it is not. Also back in those times, hot-dip galvanizing was considered a “quick” process, where flame-spray metal application was thought to be tedious and expensive.

The protective layer produced is significantly different between the two processes. Because of the strong chemicals, high temperatures and molten zinc used in hot-dip galvanizing, the galvanized steel surface actually has an alloy effect. A hot-dip galvanized surface has highly reactive, nearly pure zinc at the exposed surface, but going down toward the substrate, there are distinct layers of zinc-iron alloy, ending up with all iron at the bottom of the galvanizing layer.

Thermal-spray metal-coated steel is different, whether the metal used is aluminum or...
zinc. The flame or arc melts the protective metal and the gas or air stream breaks the molten metal into tiny spheres, which are then deposited onto the steel to be protected. Molten metal oxidizes readily, so the tiny molten spheres have formed a thin layer of surface oxide by the time they land on the surface to be protected. They have also cooled significantly, so they do not form a continuous solid metal film, the way hot-dip galvanizing does, but the oxide layer of the metal droplets is in intimate contact with the oxide layer of surrounding droplets and any porosity between droplets is quickly filled in by oxide formation. Think of the steel substrate covered with a thick layer of M&M candies — the candy shell is the oxide layer, and the chocolate inside is the aluminum or zinc metal. In a relatively short period after application of the thermal spray metal, the “candy coating” oozes together without the chocolate inside ever melting.

The thermal-spray metal protective film is actually closer to a liquid-applied coating than to hot-dip galvanizing, except that there is no binder resin, as there would be in a liquid-applied coating.

From its first availability, thermal-spray application was useful for field work, for maintenance, and for the fact that thermal spray metal could be repaired in the field where hot-dip galvanizing could not. Another advantage of thermal-spray coating was the ability to use aluminum instead of zinc as the protective metal. Both aluminum and zinc are anodic, sacrificial metals, but aluminum sacrifices much more slowly than zinc; thermal-spray aluminum (TSA)-coated structures were found to have much longer service life than hot-dip galvanized structures. There was no “hot-dip aluminizing” process available, so taking advantage of aluminum’s lower sacrificial tendency coupled with the fact that the oxide layer formed during thermal-spray application slowed anodic metal sacrifice even more, made TSA application a viable competitor of hot-dip galvanizing.

Usable service life of 30 and 40 years in exposed severe marine environments became the accepted — and expected — norm for TSA-coated, exposed, carbon-steel structures.

The mitigation of corrosion under insulation (CUI) has a much shorter history than thermal-spray metal coating of steel. Until fairly recently, the whole concept of preventing CUI in refineries and chemical plants was totally neglected. To quote the global nonmetallic coatings specifier for a major oil company in 2009, “...when our plants were built, industry did not understand that the environment under insulation was going to be almost like immersion conditions, so the correct type of coating (immersion grade) was not used. As a result, almost NONE of the surfaces under insulation in every single facility which is older than 15 years old are adequately protected from CUI. CUI is a phenomenon because of our ignorance.”

Until the late 1970s, petrochemical equipment designers and maintenance managers worked under the incorrect assumptions that insulated, hot-operation carbon steel equipment stayed hot enough not to have water under the insulation, and that any corrosion which might occur could be offset by designing equipment with additional steel wall thickness as a “corrosion allowance.” Both of these concepts are partially incorrect.

All hot operating equipment cycles hot to cold. Even a vessel or pipe which runs hot continuously until taken down for turnaround maintenance is cycling. The length of the cycle is equal to the operating time between turnarounds, and the vessel or pipe will corrode while shut down for turnaround. Additional steel wall thickness may provide some added service life, but corrosion is rarely flat and uniformly distributed across the surface of a pipe or vessel — pinholes or cracks at welds, corners or low spots in the insulation where water may gather under the insulation will eventually perforate the steel, and the results of the perforation can be catastrophic.

Another reason for neglecting CUI was far more straightforward. Until the 1980s, there were very few coatings suitable for use in hot service under insulation. The standard process operating temperature for hot-operation carbon steel equipment in the 1980s was quoted as 350 F. During turnaround steam-out work, this temperature could reach over 400 F. Only inorganic zinc and thin-film silicones had resins which could survive such temperatures. Inorganic zinc was a sacrificial coating; once the zinc had all sacrificed, there was no longer any protection. Silicones could not be built to sufficient thickness to prevent water permeation and even with lead and chromates in the silicone primer, they did not provide adequate corrosion resistance.

Fig. 2: A large refinery or petrochemical plant will have hundreds of insulated process vessels and hundreds of miles of insulated pipe feeding those vessels.

Fig. 3: This coupon failed the thermal-spray bend test after testing as specified in SSPC-CS 23.00/AWS C2.23M/NACE No. 12.
A series of major CUI-related equipment failures in the early 1980s showed the problem with using inorganic zinc under insulation. As long as there was zinc left, the coating system protected. Once the zinc was completely sacrificed, active corrosion progressed rapidly. There was no cost-effective way of knowing or judging when the last bit of zinc was gone, and the concept of risk-based inspection had not yet been developed.

There was an active search for relatively thick-film, stable, temperature-resistant, cyclic-service-tolerant protective coatings to be used under insulation. Attempts to formulate coatings using the ethyl silicate resin from inorganic zinc, but without the added zinc, were a complete failure. The introduction of polysiloxane-based elevated-temperature coatings in the early 1990s allowed thick-film build and temperature resistance, but the initial formulations could not tolerate cyclic service. Second-generation polysiloxane-silicone hybrid formulations resolved this problem and provided the necessary temperature tolerance, flexibility for cyclic service and film thickness to survive for years under insulation. TSA coating was suggested as a CUI coating at about the same time.

Although thermal-spray application required an arc or flame, it was actually less hazardous than applying liquid paint. A “hot-work” permit similar to one issued for welding or cutting was obtained for thermal-spray application. Because the deposited metal was cool, the aluminum dust generated as overspray was less hazardous than the solvents released during liquid paint application and the dust could be easily gathered and removed, unlike paint overspray which stuck to everything it touched.

When coatings contractors first offered thermal-spray application in the 1990s and early 2000s, the cost of field application was typically about 10 times as expensive as liquid coatings. These costs included the cost of surface preparation, coating materials, application and inspection, but made no allowance for the amount of time actually required for application and drying, or for the cleanup and disposal costs at the end of the project.
Liquid coatings intended for CUI service typically require two or three coats to achieve the specified 10-to-12 mils dry-film thickness (DFT). Applied DFT for each coat cannot be accurately checked until the coat of paint is dry, which may take 8-to-12 hours, depending on temperature, humidity and air circulation. If low DFT is found, additional paint must be applied, requiring another full coat’s drying time.

In contrast, thermal-spray metal coating is a single-coat system; dry and ready to be checked for DFT within seconds of application; and any low-DFT areas that are found can be immediately touched up with additional thermal-spray metal (Fig. 4).

So Why is Thermal Spray More Expensive?

The source of the extra costs is detailed in the joint SSPC/AWS/NACE standard for application of thermal spray coatings, SSPC-CS 23.00/AWS C2.23M/NACE No. 12, “Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel” (Fig. 3, p. 64). This standard is used for thermal-spray coatings, whether intended for exposed or CUI service and the requirements in it are much stricter than requirements for application of liquid coatings in similar service.

The first bit of expensive news in this standard regards surface preparation. SSPC-SP 5, “White Metal Blast Cleaning” is required for thermal spray in marine or immersion service. Because CUI service is considered intermittent immersion, SSPC-SP 5 is mandatory for thermal spray in CUI service. Achieving a specified anchor profile is also critical for thermal-spray projects, since mechanical adhesion of the thermal-spray layer to the anchor profile of the steel substrate is the only thing keeping the thermal-spray layer attached to the substrate. Many CUI-rated liquid coatings may be applied over lesser surface preparation, or even on top of existing old coatings; the liquid resin in these provides an additional means of adhesion.

Second is the requirement for qualified applicators and helpers. Improperly applied thermal spray may have holidays or poor cohesion. Improperly applied thermal-spray coating which does not tie into the anchor profile may disbond from the substrate during thermal cycling under insulation. Thermal spray can only be applied by specialized arc-spray or flame-spray equipment; liquid coatings can be sprayed, rolled, brushed or even applied by a mitt or dauber, depending on surfaces to be coated, product data sheet or specification.

Third is the need for much more thorough inspection, before, during and after application of thermal spray, than would normally be done for liquid coatings. Properly applied TSA looks...
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like “White Metal” blasted steel, so visual holiday inspection cannot be done as for liquid coatings (Fig. 5). DFT readings must be taken much more frequently than would normally be specified by SSPC-PA 2, and pull-off adhesion testing is mandatory according to SSPC-CS 23.00.

As more and more contractors have become familiar with thermal-spray coating application, prices have come down, but they are still higher than coating the same project with liquid paint. However, thermal spray has two inherent advantages offsetting the restrictions from the SSPC/AWS/NACE standard. Unlike a contractor, who is bidding the time and materials his crews will actually use, the specification engineer or maintenance manager is also intimately concerned with the out-of-service time required to replace a CUI coating system on a vessel or pipe run. To him or her, “out of service” means “out of production.” “No production” equals “no income” for the affected unit — and possibly other units upstream or downstream in the same train, which cannot operate when the affected unit is down.

Scaffolding, tenting, removal of jacketing and insulation, surface preparation, and replacement of insulation and jacketing are identical whether using thermal spray or liquid coatings, but where liquid coating application takes three days if drying time between coats is included, thermal spray is a one-day operation. The corrosion control manager at a major Gulf Coast refinery estimated that a 15- or 17-
story contact process tower such as the ones shown in Figure 1, generates a million dollars in revenue per day of operation. Saving two days of downtime by applying thermal spray instead of liquid coating will save the owner $2 million which (the corrosion control manager estimated) is much more than the added cost of thermal spray instead of liquid coating.

The second savings is length of service life. From a contractor’s viewpoint, the cost of a project is the cost of time and materials his crews and inspectors will require to complete a project. From the corrosion control manager’s point of view, the true cost of a project is the contractor’s invoice plus the cost of out-of-service time, divided by the number of years of service life expected from the corrosion-control project.

Major U.S. oil company corrosion-control specifications rate thermal-spray aluminum in CUI service as an expected service life of 20, 30, and in one specification, 40 years without replacement or major repair. These same specifications rate the best liquid-applied coating systems as having expected service life of 8-to-15 years. From this perspective, the price of thermal-spray coating goes from being much more expensive than liquid-applied coatings to being much less expensive, since it is expected to last much longer.

Despite thermal-spray metal coating’s nearly a century of successful service on exposed steel in coastal, marine and similar severe environments, the longest properly recorded, properly monitored CUI service for TSA on U.S. refineries or chemical plants that the author can find records for is just short of 15 years. But after that service time, the applied TSA coating is in excellent shape and looks to be good for another ten or fifteen years, approaching the corrosion control manager’s dream of the CUI coating system having the same expected service life as the unit itself.

About the Author
Peter Bock is executive vice president of Advanced Polymerics Inc. in Hooksett, New Hampshire. He is an Air Force veteran and holds degrees from Tulane University and the University of Northern Colorado. Bock has 37 years of sales, management and technical service experience in oilfield and petrochemical heavy-duty coatings in the United States, Canada, Mexico, Venezuela, Indonesia and Taiwan.

He has experience with on- and offshore production, drilling and workover rigs, shipyard work, natural gas and LNG, pipelines, terminals, refineries and chemical plants. Bock is a specialist in elevated temperature systems, corrosion under insulation and chemical passivation.

He is a former president of NACE New Orleans Section and of the Houston Coating Society. Bock is a NACE-certified coating inspector and has presented papers and symposia at many national, regional and local coatings and corrosion control events.
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