Chapter 5
Thermal Spray Coating Selection

5-1. Introduction

A systematic approach to coating selection for new construction and maintenance thermal spraying is described in this chapter. Paragraph 5-2 discusses criteria important to the selection of thermal spray coatings including the service environment, expected longevity, ease of application, and maintainability. Paragraph 5-3 discusses the relative merits of paint coatings and thermal spray coatings including durability and environmental considerations. Subsequent paragraphs discuss thermal spray coating systems for specific USACE applications.

5-2. Service Environments

Foreknowledge of the environmental stresses to which the protective coating system will be exposed is critical for proper selection of the coating system. This is true of both paint and thermal spray coating systems. Exposure environments typically encompass one or more of the following environmental stresses: extremes of temperature, high humidity, immersion, extremes of pH, solvent exposure, wet/dry cycling, thermal cycling, ultraviolet exposure, impact and abrasion, cavitation/erosion, and special exposures. The service environment is the single most important consideration in the selection of a coating system.

a. Extremes of temperature. Most exposure environments show some variability in temperature. Normal atmospheric service temperatures in northern latitudes of the continental United States vary from -23 to 38 °C (-10 to 100 °F). Temperatures for immersion exposure show somewhat less variation and typically range from about -1 to 27 °C (30 to 80 °F). These normal variations in temperature are relatively insignificant to the performance of thermal spray coatings of zinc, aluminum, and their alloys. Paint coating performance is generally more sensitive to these normal extremes of temperature. Some components, such as the stacks of floating plants, may be subject to higher than normal atmospheric temperatures. With some exceptions, most paint coatings will not perform well at these elevated service temperatures. Most alkyd paints such as CID A-A-2962 will tolerate temperatures up to only about 120 °C (250 °F). Special black bituminous coatings such as CID A-A-3054 will withstand temperatures up to 204 °C (400 °F). Color pigmented modified and unmodified silicone coatings may °F) and 315 °C (600 °F), respectively. Aluminum and carbon black pigmented silicone coatings may perform at temperatures as high as 650 °C (1200 °F). Special ceramic frit coatings may perform at temperatures of 760 °C (1400 °F). SSPC Paint 20 Type I-B or I-C inorganic zinc-rich coatings can usually perform at temperatures up to 400 °C (750 °F). Thermal spray coatings of aluminum, zinc, and their alloys will provide long-term performance superior to paint coatings at temperatures approaching their respective melting points of 660 °C (1220 °F) and 420 °C (788 °F). Because of its excellent temperature resistance and corrosion protection, the aluminum thermal spray system 8-A from CEGS-09971 is recommended for applications where temperatures will exceed 400 °C (750 °F). Below this temperature, the specifier may elect to use paint system number 10 from CEGS-09965 which consists of two coats of SSPC Paint 20 Types I-B or I-C.

b. High humidity. High humidity is often accompanied by condensation, which is considered to approximate the severity of freshwater immersion. All of the thermal spray systems described in CEGS-09971 will also perform well in high-humidity condensate exposures. System 5-Z-A is the recommended thermal spray system for high-humidity condensate environments. Typically, high-performance paint systems such as the epoxy and vinyl systems described in CEGS-09965 are specified for high-humidity applications. Because paint systems are generally less costly to apply, they are more likely to be used for these types of exposures. However, thermal spray system 5-Z-A should have a longer service life than paint coatings for this application.

c. Immersion. Immersion exposures range from immersion in deionized water to immersion in natural waters, including fresh water and seawater. Ionic content and pH contribute to the corrosivity of immersion environments. Typical sealers and topcoats are vinyl paints V-766e, V-102e, V-103c, and V-106d and coal tar epoxy coating C-200A. Several of the epoxy systems and all of the vinyl systems described in CEGS-09965 are appropriate for various immersion exposures depending on whether the water is fresh or salt and the degree of impact and abrasion. The epoxy systems are preferred for saltwater exposures, while the vinyl systems are generally preferred for freshwater exposures, especially where the level of impact and abrasion is significant.

(1) Seawater. Aluminum thermal spray system 8-A described in CEGS-09971 is recommended for seawater immersion. Aluminum thermal spray has been used extensively by the offshore oil industry to protect immersed and splash zone platform components from corrosion. Aluminum thermal spray is thought to perform better in seawater immersion without an organic sealer and paint topcoat.

(2) Fresh water. Thermal spray systems 5-Z-A and 6-Z-A are recommended for freshwater immersion, with 6-Z-A being the preferred choice for more severe exposures. These systems can be used either with or without sealers and topcoats.

d. Extremes of pH. Extremes of pH, such as strongly acidic or alkaline environments can greatly affect coating performance. The coating must be relatively impermeable to prevent migration of the acidic or alkaline aqueous media to the substrate, and the coating material itself must be resistant to chemical attack. Thermal spray coatings of aluminum, zinc, and their alloys may perform poorly in both high and low pH environments. Both metals show increased solubility as pH increases or decreases from the neutral pH of 7. Thermal spray aluminum and zinc may be used in acidic or alkaline environments provided that they are sealed and topcoated with vinyl or epoxy coatings. Unsealed zinc thermal spray coatings are suitable for pHs of 6 to 12 and aluminum thermal spray coatings for pHs of 4 to 8.5. Thermal spray coatings containing zinc or aluminum should not be used in chemical environments where they may be exposed to strong acids such as battery acids. Alkyd paints generally have poor resistance in alkaline environments. The epoxy and vinyl systems described in CEGS-09965 perform well in mildly acidic and alkaline environments. Topcoats with aluminum pigmentation should not generally be used in these exposures. Organic coatings and linings, as well as special inorganic building materials, should be used in highly alkaline or acidic environments.

e. Solvent exposure. Solvent exposure covers a wide variety of solvent types. Thermal spray metal coatings are essentially unaffected by solvent exposure and are good candidates for service in such environments. Some owners exclude the use of all zinc-containing coatings from use in aviation fuel storage tanks because metal contamination may affect the performance of the fuel. A solvent exposure that may be harsher on thermal spray coatings than anticipated is petroleum storage tanks where a layer of corrosive water can collect on the inside bottom of the tank. The water results in a much more corrosive environment than would be assumed if only the petroleum product was present. Some blends of organic solvents or natural petroleum products may also be acidic, which may affect thermal spray coating performance. Normal exposures to organic products such as cleaning solvents, lubricants, and hydraulic fluids should not preclude the use of thermal spray coatings of aluminum, zinc, and their alloys at USACE projects. The performance of paint coatings in solvent exposures depends on the coating type and the solvent species. Specific paint types, such as epoxies, are more solvent resistant than others. Some solvent types are more aggressive than others, independent of coating type.

f. Wet/dry cycling. Alternating wet and dry conditions are normal for most atmospheric exposures and, as such, most coating systems will provide adequate protection under such conditions. Thermal spray metal coatings will provide excellent performance under normal atmospheric conditions. Sealing and topcoating of the thermal spray coating is not generally necessary for such simple exposures. Generally, coating system selection will depend more on other stresses in the environment than on simple wet/dry cycling.

g. Thermal cycling. Thermal cycling may result from normal diurnal temperature variations as well as temperature changes found in operating machinery and process vessels. Thermal cycling induces stresses within the coating. Thermal sprayed metal coatings are more apt to have coefficients of expansion similar to the substrate; therefore, their relative inflexibility does not cause them to fail under normal conditions of thermal cycling.

h. Ultraviolet exposure. Resistance to ultraviolet (UV) radiation induced degradation is an important aspect of coating performance. All thermal sprayed metallic coatings are essentially unaffected by UV radiation. Organic sealers and topcoats used over thermal spray coatings will be affected the same as any other paint material of the same type. Organic paint coatings are affected by UV radiation to varying degrees. Depending on the coating resin and pigmentation types, UV degradation may result in loss of gloss, color fading, film embrittlement, and chalking. Certain paints, including silicone and aliphatic polyurethane coatings, exhibit superior UV resistance. Some coatings, including most epoxies and alkyds, have fairly poor UV resistance.

i. Impact and abrasion. Impact and abrasion are significant environmental stresses for any coating system. Abrasion is primarily a wear-induced failure caused by contact of a solid material with the coating. Examples include foot and vehicular traffic on floor coatings, ropes attached to mooring bitts, sand suspended in water, and floating ice. When objects of significant mass and velocity move in a direction normal to the surface as opposed to parallel, as in the case of abrasion, the stress is considered impact. Abrasion damage occurs over a period of time while impact damage is typically immediate and discrete. Many coating properties are important to the resistance of impact and abrasion including good adhesion, toughness, flexibility, and hardness. Thermal spray coatings of zinc, aluminum, and their alloys are very impact resistant. Zinc metallizing has only fair abrasion resistance in immersion applications because the coating forms a weakly adherent layer of zinc oxide. This layer is readily abraded, which exposes more zinc, which in turn oxidizes and is abraded. Thermal spray coating system 6-Z-A described in CEGS-09971 is considered to be the most impact/abrasion resistant of all of the Corps' coating systems. Application of this system to tainter gates in very harsh environments has been shown to be highly effective. The vinyl paint systems described in CEGS-09965 are particularly resistant to impact damage caused by ice and floating debris, but are less resistant than metallizing. The epoxy systems are somewhat brittle and are not nearly as resistant to impact damage as are the vinyls.

j. Cavitation/Erosion. More severe than impact and abrasion environments are exposures involving cavitation and erosion. Cavitation results when very-high-pressure air bubbles implode or collapse on a surface. The pressures involved can be very high (413,000 to 1,960,000 kPa (60,000 to 285,000 psi)) and destructive. Metallic components of hydraulic equipment such as hydroelectric turbines, valves and fittings, flow meters, hydrofoils, pumps, and ship propellers are particularly susceptible to cavitation damage. Low, medium, and high severity of cavitation have been defined based on an 8000-hr operating year. Low cavitation is defined as loss of carbon steel in the range 1.6 to 3.2 mm (1/16 to 1/8 in.) over a 2-year period. Medium cavitation is loss of austenitic stainless steel at greater than 1.6 mm (1/16 in.) per year. High cavitation is loss of austenitic stainless steel greater greater than 3.2 mm (1/8 in.) in a 6-month period. The standard method of repairing cavitation damage is to remove corrosion products by gouging with an electric arc and then grinding the damaged area. The cleaned area is then filled with weld metal and redimensioned by grinding. This method is very time consuming and expensive. Very hard and dense thermal spray deposits applied by HVOF spray have been used on an experimental basis as cavitation resistant materials and in conjunction with weld overlays as a repair technique.

k. Special exposures. Special exposures may include the coating of surfaces governed by the Food and Drug Administration (FDA) and National Sanitation Foundation (NSF) for food and potable water contact, respectively. Guide specifications CEGS-09965 and CEGS-09971 do not address either of these applications. Another special exposure is the use of coatings to prevent macrofouling caused by either marine fouling organisms or zebra mussels. Many of the coatings used to control fouling contain a toxin, which must be registered with the Environmental Protection Agency under the requirements of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Corps guidance documents do not address the use of coatings to control fouling organisms, however thermal spray systems containing zinc and/or copper are known to be effective zebra mussel deterrents. Thermal spray coating systems 6-Z-A and 3-Z described in CEGS-09971 are recommended control coatings for zebra mussels on immersed steel and concrete surfaces. Neither material requires FIFRA registration.

5-3. Other Considerations in Coating Selection

The specifier should also consider other aspects of the proposed coating job in order to select the most appropriate coating system. Other factors discussed below include limits on surface preparation, ease of application, regulatory requirements, field conditions, maintainability, and cost.

a. Limits on surface preparation. Coating selection may be limited by the degree or type of surface preparation that can be achieved on a particular structure or structural component. Because of physical configuration or proximity to sensitive equipment or machinery, it may not always be possible to abrasive-blast a steel substrate. In such cases, other types of surface preparation, such as hand tool or power tool cleaning, may be necessary, which, in turn, may place limits on the type of coatings that may be used. In some cases, it may be necessary to remove the old coating by means other than abrasive-blasting, such as power tools, water jetting, or chemical strippers. These surface preparation methods do not impart a surface profile that is needed by some types of coatings to perform well. In the case of thermal spray coatings, a high degree of surface preparation is essential. This kind of preparation can only be achieved by abrasive blasting with a good quality, properly sized angular blast media. Thermal spray should never be selected for jobs where it is not possible to provide the highest quality surface preparation.

b. Ease of application. Coating selection may be limited by the ability of the applicator to access the surfaces to be coated. This usually is the result of the physical configuration or design of the structure. Items of limited access such as back-to-back angles, cavities, and crevices may be difficult if not impossible to coat. Most items that can be coated by paint spray application may also be coated by thermal spray. Both methods require about the same amount of access area for hoses, maneuvering, and standoff distance. As a rule of thumb, if access to the surface allows proper blast cleaning, then thermal spray application is feasible. Thermal spray coatings perform best when sprayed in a direction normal to the surface and within a particular range of standoff distances from the substrate. Application at an angle of less than 45 deg to the vertical is not recommended. Maximum and minimum standoff distances depend on the material being applied, the manufacturer, and the type of thermal spray equipment. If the standoff distance and spray angle cannot be maintained within the specified range, hand application of a paint coating may be necessary.

c. Regulatory requirements. The use of paint coatings is regulated in terms of the type and amounts of solvents or volatile organic compounds (VOC) they contain. Certain types of solvents, such as water and acetone, are exempt from these regulations because they do not contribute to the formation of photochemical pollution or smog in the lower atmosphere. Regulations vary by geographic location and by industry. Different rules apply for architectural and industrial maintenance painting, marine painting, and miscellaneous metal parts painting. USACE field painting is considered architectural and industrial maintenance painting. Shop painting performed by a fabricator is considered miscellaneous metal parts painting. Painting of a floating plant in a shipyard or dry dock facility is considered marine painting. The specifier should consult with local and state officials to determine which rules, if any, affect the proposed coating work. There are no VOC emissions associated with the use of thermal spray coatings, and their use is not regulated by any such rule. Thermal spray coatings offer an excellent VOC compliant alternative to paint coatings for many applications. The sealers and topcoats recommended for thermal spray systems are not exempt from VOC-type regulations. The thermal spray coatings will often perform just as well without the sealers and topcoats, which can therefore be omitted for reasons of compliance with air pollution regulations. It should also be noted that there are typically low VOC paint coating alternatives for most applications. The relative merits of these products should be weighed against those of the zero VOC thermal spray coating systems.

d. Field conditions. The conditions under which the coating work will be performed are another important consideration in coating selection. Certain atmospheric conditions, including high humidity and condensation, precipitation, high winds, and extreme cold or heat, place severe limitations on any type of coating work.

(1) Moisture on the surface should always be avoided to the greatest extent possible. Certain types of paint are more tolerant of small amounts of water on the surface and should be specified for work where such conditions cannot be avoided. Thermal spray metal coatings should never be applied if moisture is present on the surface.

(2) High winds may affect the types of surface preparation and coating application methods that are practical for a given job. High winds will tend to carry surface preparation debris and paint overspray longer distances. This problem can be avoided by using methods other than open abrasive blasting and spray application of paints.

(3) The pot life of multicomponent catalyzed coatings such as epoxies can be greatly reduced by high atmospheric temperatures. High ambient air and surface temperatures can also adversely affect paint application and the subsequent performance of the coating; for example, vinyl paints are prone to dry spray at high temperatures. Most paints should not be applied below a certain minimum temperature because they will not cure or dry. Most epoxy paints should not be applied when ambient and substrate temperatures are below 10 °C (50 °F); however, there are some specialized epoxy coatings that can be applied at temperatures as low as -7 °C (20 °F). Latex coatings should never be applied when temperatures are expected to fall below 10 °C (50 °F) during application and drying. Vinyl paints can be applied at quite low temperatures compared with most paints. Vinyl application at 0 °C (32 °F) can be performed with relative ease. There are generally no upper or lower ambient or surface temperature limits on the application of thermal spray coatings, although there are practical limits at which workers can properly perform their tasks. In thermal spray, the steel substrate is generally preheated to well above ambient temperatures to drive off any latent moisture and to prevent condensation from forming on the surface. In addition, any ill effects that a cold substrate might have are ameliorated.

e. Maintainability. The future maintainability of the coating system should be considered by the specifier. Some protective coatings are easier to maintain than are others. The specifier should also be cognizant of how maintenance painting is normally achieved, whether by contractor or with in-house labor. In-house labor is usually sufficient for low technology processes that require minimal training and equipment. For example, touch-up painting with brushes or rollers of paints exposed to the atmosphere is readily accomplished with in-house labor. More sophisticated dedicated in-house paint crews can accomplish more complicated work including abrasive blasting and spray application of paints for immersion service. Thermal spray coating and maintenance, because of their specialized nature and relatively high equipment cost, are ordinarily best accomplished by contract. Thermal spray coatings are also more difficult to repair than are most paint coatings. The ease of spot repair of thermal spray metal coatings approximates that of the vinyl paint systems. As with the vinyls, special care must be taken to properly feather the edges of the blast-repaired areas without causing adjacent coating to disbond or lift from the surface. Because of the difficulty affecting appropriate repairs, the thermal spray coating systems, like the vinyls, are generally kept in service until total recoating is needed.

f. Cost. Coating systems are cost effective only to the extent that they will provide the requisite corrosion protection. Cost should be considered only after the identification of coatings that will perform in the exposure environment. Given that a number of coating systems may perform for a given application, the next consideration is the cost of the coating job. Ideally, protective coating systems will always be selected based on life-cycle cost rather than simple installed cost. However, given the realities of budgets, this approach is not always practical.

Therefore, coating systems are sometimes selected on the basis of first or installed cost. Because thermal spray coating systems are almost always more expensive to install than paint systems for a given application, they are often passed over, when, in fact, they can have significantly lower life-cycle costs than paint systems. For additional information on the cost of thermal spray and how to perform cost calculations, refer to paragraph 4-2 of this manual.

5-4. Thermal Spray Selection for Ferrous Metal Surfaces in Fresh Water

All of the thermal spray systems described in CEGS-09971 will perform in freshwater immersion service. The 85-15 zinc-aluminum systems designated as systems 4-Z-A, 5-Z-A, and 6-Z-A are considered to have optimal properties for freshwater service, combining the superior corrosion resistance of zinc and the improved impact and abrasion resistance of aluminum. The more severe the service, the thicker the coating should be, with system 6-Z-A being the recommended choice for highly turbulent ice- and debris-laden waters. System 5-Z-A is the first choice for relatively quiet nonabrasive waters. Seal coats and paint topcoats may be used to add a further degree of protection to the thermal spray coating systems used in freshwater immersion but their use is not considered an absolute necessity. Table 5-1 identifies a number of typical components exposed to freshwater environments and the recommended and preferred thermal spray systems.

5-5. Thermal Spray Selection for Ferrous Metal Surfaces in Seawater

Again, all of the thermal spray systems described in CEGS-09971 will perform in seawater immersion service. Aluminum thermal spray coatings have seen much wider use in marine environments, and they are generally preferred over the zinc-containing coatings for seawater immersion. System 8-A is the recommended thermal spray system for this application. Seal coats and paint topcoats may be used to add a further degree of protection to the thermal spray coating systems used in seawater immersion, but their use is not considered an absolute necessity. Table 5-2 identifies a number of typical components exposed to seawater environments and the recommended and preferred thermal spray systems.

5-6. Thermal Spray Selection for Ferrous Metal Surfaces Exposed to the Atmosphere

Table 5-3 identifies a number of typical components exposed to the atmosphere and the recommended and preferred thermal spray systems.

a. Marine and normal atmospheric exposives. All of the thermal spray systems described in CEGS-09971 will perform in both marine and normal atmospheric exposures. Aluminum thermal spray system 7-A is generally preferred for atmospheric applications where a significant amount of salt can be expected to be deposited on the coated surfaces. These applications include coastal marine structures and bridges exposed to deicing salts. Sealing and topcoating the aluminum thermal spray is optional and may be done for aesthetic reasons or to improve the overall performance of the coating system.

b. Mild atmospheric exposures. Structures in less severe atmospheric environments such as rural areas should be coated with either zinc or zinc-aluminum alloy systems 1-Z and 4-Z-A, respectively. Again, sealing and topcoating the thermal spray coating for such mild atmospheric exposures is not necessary but may be done to increase the service life of the coating system or to alter the appearance.

Table 5-1
Recommended Thermal Spray Systems for Freshwater Immersion

Components	Thermal Spray Systems from CEGS-09971[a]	Sealers
Penstocks, spiral cases, spiral case extensions, draft tube liners, and surge tanks	2-Z, 3-Z, 5-Z-A, **6-Z-A**, 8-A	1 coat C-200A
Crest gates	2-Z, 3-Z, 5-Z-A, **6-Z-A**, 8-A	2 coats V-766e or 1 coat V-766e + 1 coat V-102e or none
Control gates and valves of reservoir outlet works	**6-Z-A**, 8-A	2 coats V-766e or none
Trashracks for water intakes	**6-Z-A**	None
Navigation lock gates and valves	5-Z-A, **6-Z-A**, 8-A	2 coats V-766e or 1 coat V-766e + 1 coat V-102e or none
Navigation dam gates	**6-Z-A**	2 coats V-766e or 1 coat V-766e + 1 coat V-102e or none
Freshwater tanks	2-Z, 3-Z, 5-Z-A, **6-Z-A**, 8-A	1 coat C-200A or none
Equipment for local flood protection projects	Not recommended	
Exterior surfaces of steel hulls	**6-Z-A**, 8-A	2 coats V-766e or 2 coats V-106d or 1 coat V-766e + 2 coats V-103c
Wet interior surfaces of steel hulls	2-Z, **3-Z**, 5-Z-A, 6-Z-A, 8-A	None

[a] System in boldface is preferred.

Table 5-2
Recommended Thermal Spray Systems for Seawater Immersion

Components	Thermal Spray Systems from CEGS-09971[a]	Sealers
Steel piling	**8-A** (from just below mud line to 0.9 m (3 ft) above high-water line)	2 coats V-766e or 1 coat V-766e + 1 coat V-102e
Trashracks for water intakes	6-Z-A, **8-A**	None
Navigation lock gates and valves	6-Z-A, **8-A**	2 coats V-766e or 1 coat V-766e + 1 coat V-102e
Exterior surfaces of steel hulls	6-Z-A, **8-A**	2 coats V-766e or 2 coats V-106d or 1 coat V-766e + 2 coats V-103c

[a] System in boldface is preferred.

c. Severe atmospheric exposures. For severe atmospheric exposures such as industrial areas with acid rain, an aluminum thermal spray system should be used. Thermal spray coatings exposed to corrosive industrial atmospheres or chemical fumes should always be sealed and topcoated.

5-7. Thermal Spray Selection for Ferrous Metal Surfaces Exposed to High Temperatures

Thermal spray coatings of aluminum, zinc, and their alloys will provide excellent long-term performance at temperatures approaching their melting points. The maximum recommended service temperature for zinc systems 2-Z and 3-Z is 60 °C (140 °F). The maximum recommended service temperature for 85-15 zinc-aluminum alloy systems 5-Z-A and 6-Z-A is 315 °C (600 °F). Aluminum thermal spray is an excellent choice for high-temperature applications. System 8-A, described in CEGS-09971, is the preferred system for civil works applications such as stacks of floating plants, where the surface temperature is expected to exceed 400 °C (750 °F). The high-temperature performance of aluminum thermal spray coatings can be further improved by post-heating or fusing of the aluminum to the steel substrate. Fusing is ordinarily accomplished by reheating the aluminum thermal spray coating with oxyacetylene torches. This process fuses the aluminum and steel substrate, creating a metallurgical bond. Coating performance may be further enhanced by applying a seal coat of an aluminum pigmented bitumastic coating. Such coatings can provide corrosion resistance against hot gases at

Table 5-3
Recommended Thermal Spray Systems for Atmospheric Exposures

Components	Thermal Spray Systems from CEGS-09971[a]	Sealers
Exterior surfaces penstocks	2-Z, 3-Z, **5-Z-A**, 6-Z-A, 8-A	1 coat CID A-A-3127
Exterior surfaces of surge tanks	2-Z, **3-Z**, 5-Z-A, 6-Z-A, 8-A	1 coat CID A-A-3127
Service bridges	1-Z, **2-Z**, 3-Z-A, 4-Z-A	2 coats TT-P-38 or 1 coat CID A-A-3127 or 2 coats CID A-A-3132 or 1 coat SSPC Paint 27 + 1 coat A-A-2962
Exterior surfaces of steel tanks	1-Z, **2-Z**, 3-Z-A, 4-Z-A	2 coats TT-P-38 or 1 coat CID A-A-3127 or 2 coats CID A-A-3132 or 1 coat SSPC Paint 27 + 2 coats A-A-2962
Steel decks (nonskid)	**8-A**	1 coat CID A-A-3127 or 2 coats CID A-A-3132
Stacks of floating plants		2 coats TT-P-28
Temp. < 345 °C (650°F)	**6-Z-A**	or 2 coats silicone alkyd
Temp. > 345 to 595 °C (650 to 1100°F)	**8-A**	
Dry interior surfaces of steel hulls	**1-Z**, 2-Z, 3-Z-A, 4-Z-A	None
Steel surfaces in marine atmospheres	3-Z-A, 4-Z-A, 7-A, **8-A**	2 coats TT-P-38 or 1 coat CID A-A-3127 or 2 coats CID A-A-3132 or 1 coat SSPC Paint 27 + 1 coat A-A-2962 or 2 coats V-766e or 1 coat V-7662 + 1 coat V-102e

[a] System in boldface is preferred.

temperatures of up to 870 °C (1600 °F). Thermal spray coatings may not be practical for some high-temperature applications. Thin steel substrates cannot usually be blast-cleaned to create the profile needed for thermal spray coatings without warpage. Steel substrates that cannot be blast- cleaned should be painted rather than thermal spray coated for high-temperature applications. Some typical components exposed to high temperatures and the recommended thermal spray systems can be found in Table 5-3.

5-8. Thermal Spray Selection for Zebra Mussel Protection

The zebra mussel is a freshwater bivalve that colonizes hard substrates. When present in sufficient densities, the zebra mussel can impact the performance of civil works structures and floating plants. Zebra mussels can impair structure performance by occluding narrow openings and small conduits such as may be found in condenser tubes, trashracks, sea chests, fire suppression systems, etc. Zebra mussels can also reduce the efficiency of floating plants and power plants by causing hydraulic drag. Coatings are one means of preventing the attachment of zebra mussels to Corps structures. Thermal spray coatings containing zinc and/or copper have been found to be effective deterrents. Juvenile mussels will not settle on these metallic surfaces because small amounts of zinc and copper leaching into the water from the coating act as deterrents. The mussels are not actually killed but rather they sense the toxic chemicals in the water and do not attach themselves to these surfaces. Thermal spray coatings containing copper such as brass, aluminum bronze, and pure copper should not be applied to steel substrates because they will not protect the steel from corrosion and may make it worse. Copper and brass thermal spray coatings can however be applied to concrete substrates to prevent zebra mussel fouling. Zinc and 85-15 zinc-aluminum alloy coatings are a better choice for controlling zebra mussels on steel as they also serve as anticorrosive coatings. Because of their lower material costs zinc and 85-15 zinc-aluminum are probably better choices for concrete as well, even though they are slightly less effective than brass and copper. Zinc-containing coatings do not need to be registered with the EPA. Zinc is a relatively weak aquatic toxin and is an even weaker mammalian toxin, and as such, no effects on nontarget organisms should be anticipated with its prophylactic use as a zebra mussel deterrent.

5-9. Thermal Spray Coatings for Cathodic Protection of Reinforcing Steel in Concrete

Steel reinforced concrete structures such as bridges, parking decks, and piers are prone to chloride-induced corrosion. Chloride ions present in deicing salts and marine atmospheres penetrate the concrete monolith with time. The normally passivated steel rebar will begin to corrode when enough salt accumulates at the steel-concrete interface. The steel corrosion products, being more voluminous than the steel itself, cause the concrete to crack and spall. Failures of reinforced concrete systems can be very expensive to repair and are difficult to prevent. Various approaches to preventing this phenomenon have been tried with varying degrees of success including epoxy coated rebar, galvanized rebar, special concrete admixtures, and sealing the concrete to prevent chloride penetration. A more effective method of preventing chloride-induced failures is the use of cathodic protection. Zinc thermal spray can been used as either a consumable galvanic anode or as a conductive anode in an impressed current system. In the impressed current system, rectifiers are used to supply current to the conductive zinc anode via electrical connectors which are attached to the concrete. The zinc thermal spray coating is itself applied directly to the concrete. Anode design and current density are important to the overall effectiveness of the cathodic protection system. At this time there is no guidance within the Corps on the use of zinc metallized cathodic protection systems. For additional information on cathodic protection refer to EM 1110-2-2704, "Cathodic Protection Systems for Civil Works Projects," TM 5-811-7, "Electrical Design, Cathodic Protection," and ETL 1110-3-474, "Cathodic Protection."

5-10. Thermal Spray Nonskid Coatings

Nonskid coatings are sometimes used to prevent or reduce slip hazards. Aluminum thermal spray coatings have been used successfully on metal substrates to prevent corrosion and impart nonskid properties. Historically, paint coatings have been used for nonskid applications. However, because of their greater hardness and roughness, aluminum thermal spray coatings are superior for many nonskid applications. The nonskid coating system is achieved by first applying aluminum thermal spray system 8-A. An additional spray pass of aluminum is then applied using reduced atomization air pressure. The lower air pressure allows for the deposition of larger spray particles that produce a rougher surface. Nonskid coatings should be sealed with thin film epoxies. Aliphatic polyurethanes can be used for durable striping if desired. Some common applications for nonskid coatings and the recommended thermal spray coatings systems may be found in Table 5-3.

5-11. Thermal Spray Coatings for Cavitation/Erosion Protection

a. Cavitation repair and mitigation. For hydraulic components subject to low cavitation environments, Stellite 6 applied by the HVOF spray process may be used to mitigate and repair cavitation damage. The coating is applied to a thickness of 500 μm (0.020 in.) over blast-cleaned weld metal overlay for cavitation repair or directly to the blast-cleaned steel component for mitigating cavitation damage. The coating serves as a sacrificial element with improved wear resistance. With proper maintenance intervals, the coating may be replaced periodically at approximately a third of the cost of additional maintenance by weld overlay. Turbine draft tube liners and pump impellers are good candidates for the use of Stellite 6 coatings for cavitation repair and mitigation.

b. Dissimilar metals corrosion. Weld overlay repair of hydraulic components is generally performed using a stainless steel material over a carbon steel substrate. The two metals have different electrochemical potentials, and, therefore, galvanic corrosion will occur to the mild steel adjacent to the boundary of the two metals. The corrosion may be exacerbated by the erosion taking place in the cavitating environment. Stellite 6 applied by the

HVOF spray process may be used to mitigate corrosion of hydraulic components subject to dissimilar metals corrosion in erosive environments. The coating is applied to a thickness of 500 μm (0.020 in.) over the entire component, including the blast-cleaned weld metal overlay. Stellite 6 acts as an expendable wear resistance coating. Turbine draft tube liners and pump impellers are good candidates for the use of Stellite 6 coatings for corrosion mitigation. Arc plasma sprayed alumina titania ceramic powder coatings can also be used to improve and restore dimensions of pump shafts and bearings and to provide an erosion-corrosion resistant coating for impellers and interior surfaces of the casing. Alumina titania is a ceramic coating and is not subject to galvanic corrosion.

c. For additional information on methods and materials for thermal spray cavitation/erosion protection see USACERL Technical Report 97/118, "Cavitation- and Erosion-Resistant Thermal Spray Coatings," and MIL-STD-1687A(SH).

5-12. Thermal Spray Coatings for Partially Submerged Structures

Certain components of hydraulic structures may be only partially submerged. Structural components that are partially immersed in either seawater or fresh water should be coated with the appropriate thermal spray system for immersion. The aerial exposed portions of the structural component should be coated with the same thermal spray material of the same or lesser thickness. Alternatively, the aerial exposures may be protected with just a paint system. If this method is selected, the thermal spray sealer and the paint topcoat should be the same material. For example, a miter gate partially immersed in seawater could be metallized with aluminum system 8-A and sealed with two coats of vinyl paint V-766e. Above the waterline, the gate could be coated with aluminum thermal spray system 7-A and sealed with two coats of V-766e. Alternatively, paint system 5-E-Z, described in CEGS-09965 and consisting of a vinyl zinc-rich primer (VZ-108d) and multiple coats of gray and white vinyl (V-766e), could be used to protect the atmospherically exposed portions of the gate. Both the paint system and the aluminum thermal spray system would provide excellent protection at a reduced cost. Dissimilar thermal spray metals should never be applied to the same structural component because one of the materials may corrode preferentially to protect the other metal.