Discussion Topics and Threads on Thermal Spray

Compiled and edited by Dr. R.S. Lima, National Research Council of Canada (NRC). These questions and answers were extracted from the discussion group of the Thermal Spray Society of ASM International. The content has been edited for form and content. Note that the comments have not been reviewed. Any further discussion can be submitted to the Editor of the JTST.

Question 1

Magnetic Coating. I would like to put a magnetic coating on a specific area of a small 316 stainless steel part. The coating has to be 0.001 to 0.002 in. thick. Ideally, the coating should be a magnetic hard material such as NbFeB or SmCo. The coating will be placed in a benign environment and will not be touched after application.

Answer 1.1: The stainless steel part is not difficult to coat, providing the part can withstand a grit-blasting process to prepare the surface. My greatest concern is that even if you have a powder of a suitable size (−100/+40 μm) of either NbFeB or SmCo, what will happen to their magnetic properties when they are heated to "red heat" during spraying?

Question 2

Pitting in WC Coatings. I have sprayed WC-Co via high-velocity oxyfuel (HVOF) on pump plungers. Now the plungers have come back with lots of pits and loss of coating in the middle portion of the plungers. According to the customer, the plungers were in service for only 15 h. He also informed us that the pumps (where these coated plungers were fitted) were used in a cryogenic application, where liquid ammonia is in service.

Answer 2.1: We also have feedback from one of the fertilizer plants that an HVOF coating has failed on ammonia and carbonate pump application. There are two probable reasons for this phenomenon.

- If you have used WC-Co, the Co does not offer good corrosion resistance in an immersed application and especially in ammonia and carbonate.
- No matter how good a coating is, as-sprayed coatings will always have some porosity, and if it is not sealed properly this leads to crevice corrosion in the coating itself.

Our suggestions to have better results are listed below.

- Spray WC-Ni or WC-Ni-Cr type powders via HVOF with suitable sealant to be applied immediately after coating deposition while the part is still warm.
- Employ a Ni-Cr-Mo spray fused alloy, which will give porosity-free coatings.

Answer 2.2: What is the size of plunger? We specialize in making coatings for pump plunger and pump shaft sleeves. We have experienced many failures in both applications and observed that the spray parameters are the most important factor in coating performance. We have been coating plungers and sleeves for the last 10 years, and our coated plungers and sleeves have been working under a variety of conditions.

Answer 2.3: Something to watch for in coating plungers is the discharge pressure. Also, what is the binder in the tungsten carbide and what is the packing material being used? We used to HVOF-spray plungers and then switched back to spray and fused coatings because of peeling and the excessive packing wear on high discharge pressure plungers. The pitting could be due to binder leaching if you are using something like an 88-12 mix. In ammonia a 90-11 nickel binder has worked for us.

Question 3

Coating on the Splines of a Helicopter. *Background:* Heavy-lift helicopter used for construction, logging, and fire fighting. It employs Ti-6Al-4V forged helicopter rotor hubs. The splines of the rotor hubs are fretting, and a spray repair is needed. A low-pressure plasma spray (LPPS) coating followed by machining was tried, but the coating deteriorated (information on the coating material that was used is unavailable at this time). The stresses of reassembly caused shearing of some of the coating, and the pounding that created the original fretting caused any surviving coating to deteriorate. Air spray is unacceptable due to the risk of formation of an alpha case during processing.

Questions:

- Is there anyone that can provide a high-velocity low-pressure plasma service to replace the LPPS coating?
- Should the spline be machined before coating deposition?
- Would a soft coating material such as Cu-Ni-In (which was used in titanium disk dovetails to repair the fretting damage) be suitable or should a harder and tougher material be used?

Answer 3.1: The spraying of titanium-base alloys for this job is constrained by two main factors.

- It limits the part temperature during spray due to the phase-stability issues, as mentioned.
- For this antifretting application, the poor sliding and galling resistance of titanium alloys in general is a limiting factor.

From these points of view, the titanium coatings should be either difficult to apply or not function properly. Depending on the microslip amplitudes or if the slip is partial or large, fretting may take the form of either fretting fatigue or fretting wear. In any case, due to the certain degrees of microslip occurring, any lubricity from the coating to be applied would be somewhat effective in reducing fretting. Also, higher strength retards the crack initiation and toughness raises the resistance to crack propagation under fretting fatigue. So, the mentioned Cu-Ni-In or the chromium carbide-NiCr would be candidate materials to consider, the latter coating being tougher to a greater degree due to its higher hardness. Another class of coatings to consider might be the abradable types, such as nickel graphite. These are easy-cutting or easy-abrading coatings, but cohesively strong, lubricious, and tough. This coating also has the advantage of being sprayed at low temperature (i.e., by the flame spray process) and used in the as-sprayed state.

Question 4

Arc Spraying on Cast Iron. We need to coat the inside diameter (ID) of a coat iron pulley. The bore is about 4 in. (102 mm) in diameter and 2 in. (51 mm) in length. We have carbon steel and chromium steel in stock. If I am not mistaken, there are severe issues of bonding any coating by arc spray on cast iron. Are there any other options available or some special wire for cast iron?

Answer 4.1: We have sprayed inside diameters with our Ni-Al wire with combustion wire spray with great success. A 2 in. length with a bore of 4 in. should be easy enough even without using an ID extension. Our wire gives a coating with a bond strength exceeding 12 ksi (82 MPa). There is no limit to the coating thickness, but sometimes it is hard to machine. If you are grinding the ID after spraying, it will work wonderfully well.

Answer 4.2: It is worth it to burn/blow away loose graphite on the cast iron surface after grit blasting. A propane-air torch would do the job. Do not heat the part much, just perform a couple quick passes.

Answer 4.3: Bond layer of Ni, Ni5Al, Ni20Cr would help a lot. There should be no problems with arc spraying.

Answer 4.4: Use nickel-aluminide applied using arc wire spray on a freshly grit-blasted surface. The machining marks will actually increase surface area for the coating and enhance bond strength. Later on you can single-point machine or grind it to the blueprint specifications. If you follow surface preparation with an immediate coating buildup, oxidation of the cast iron should not be a problem.

Question 5

Crevice Corrosion in Seawater Application. Does anyone have any experience or suggestion for a coating system that can withstand crevice corrosion in a stagnant seawater application? The base metal is a duplex stainless steel 1.4462 (SAF2205), which is generally in excellent condition in wetted areas, but shows severe crevice corrosion damage under a sleeve. Corrosion damage is quite deep, so a final coating thickness of around 1.5 mm will be required.

Answer 5.1: The initial crevice dimension (e.g., the angle subtended between an O-ring/gasket/sleeve and a metal surface) can be a significant factor in whether corrosion is initiated, along with the other expected contributing factors (alloy composition, water chemistry, exposure/service conditions, etc.). This makes sense since depletion of dissolved oxygen within a water-filled crevice is what gives rise to a dissolved oxygen concentration gradient. This, in turn, leads to highly acidic (low pH) conditions that can initiate the metal dissolution. In any event, beware of general statements about this-or-that alloy being resistant to crevice corrosion, especially when based on limited case studies that may not match your specific situation.

Answer 5.2: Crevice corrosion depends on oxygen content, temperature, and alloy system. To immunize crevice or pitting corrosion, the ideal materials are those with high molybdenum content. As an added note you should also consider the use of a sealant.

Answer 5.3: The few studies I know about nickel alloys do indeed bear out what you have said—under identical exposure conditions, these molybdenum-containing alloys are far superior to steels in their resistance to crevice corrosion. However, even they can undergo such corrosion, if the "right" conditions are present. Fully identifying these conditions has been an area of ongoing research.

Answer 5.4: The first trans-Atlantic cable was pulled up from the bottom, and none of the connectors had any evidence of corrosion anywhere after more than a century immersed in the sea. These connectors had been in ocean depths ranging from near shore to miles deep and covered with anoxic muck. They were made out of beryllium-copper. Caution, use respirators when spraying this material and make certain all dust and overspray is contained. Waste material can be sold to the beryllium-copper smelters.

Answer 5.5: A number of copper alloys do quite well in resisting seawater corrosion, and the copper offers the possible added benefit of antifouling properties (at least in more oxygen-rich waters).

Answer 5.6: From the website http://ehswprod.lbl.gov/EHSTraining/Be/html/Be08.html: The most significant disadvantage of beryllium is its toxicity. Unless ventilation and/or other controls are used, small particles or chips of insoluble beryllium-containing materials that break off during machining and other processes spread through the air in the work area. Inhalation of these microscopic particles into your lungs, or even getting these particles on your exposed skin, may lead to three health problems:

- Acute beryllium disease,
- Beryllium sensitivity, and
- Chronic beryllium disease.

However, it is important to note that the mere presence of beryllium or beryllium-containing items is not a health hazard unless the potential for generating beryllium particulate is present.

Question 6

Corrosion in Sodium Hydroxide. Can anyone tell me if a solution containing 1% of sodium hydroxide could be considered a potential corrosion problem on mild steel components plasma coated with either aluminum-, titanium-, or chromium-base oxide ceramic compounds? The remaining solution chemistry is made up of ethylene glycol monobutyl ether and methyl alcohol.

Answer 6.1: Provided all measures are taken to eliminate the bimetal or galvanic corrosion between the coating to be sprayed and the mild steel substrate, the 1% sodium hydroxide will render the solution's pH to be as high as about 12. In such an apparently highly alkaline solution, an aluminum that relies on the formation of aluminum oxide film to passivate between pH = 5 to 9 will be depassivated according to the Pourbaix diagram. This means simply that the alumina making up of the passive film becomes soluble to yield aluminate anions in such over-alkaline solutions. Alumina or hydrated alumina are amphoteric; that is, they will react with a base (as said above) or acid if the conditions are right. Regarding the latter, this means, in an acidic solution with a pH lower than 4, the alumina (as in the passive film on aluminum) will dissolve to yield Al^{3+} cations. So the key certainly is to control the concentration of the base in this case and the temperature of solution, as they affect the solubility product of the solution affecting pH as a result. It is also appreciated that the alumina passive film is bound to have some difference from the alumina spray coating, and such a difference might affect the precise values of the quantities of the above, but most certainly not the overall conclusion.

Question 7

WC Coatings for Food and Pharmaceutical Applications. Does anyone have information with regard to the use of HVOF sprayed WC coatings in food or pharmaceutical applications? I am of the understanding that the FDA does not approve of the use of tungsten carbide coatings in such applications.

Answer 7.1: One of our WC-12Co coatings obtained FDA approval for possible contact with food a number of years ago. As for pharmaceutical applications, I would be very hesitant to recommend coatings without knowledge of the precise use of the coating due to the many potential corrosive reagents used in processing the vast number of drugs produced today. I am sure that WC-Co is not approved for consumption as an ingredient in either foodstuffs or pharmaceuticals.

Question 8

Thick Aluminum Coatings on Thin Substrates. I am interested in spraying thick aluminum coatings on large thin substrates. Conventional air plasma spray has resulted in too great a tensile stress in the coating for my application. Conventional variations in plasma parameters and part/torch manipulation and temperature have resulted in only modest reductions in stress. Does anyone know any trade secrets that may help me out? At this point I am ready to move to a higher-velocity spray torch. I have tried out high-velocity plasma spray conditions with small diameter nozzles, but have made only minor improvements. I am looking for advice in choosing the correct temperature and velocity plasma, HVOF, or HVAF torch to produce the desired neutral stress condition without going too compressive. Obviously, I also need to create a production-worthy process with good deposition rates to achieve thick coatings on large parts.

Answer 8.1: Have you tried wire processes? Is coating density an important property? We have experience with developing a shell made completely of sprayed aluminum. The trick seemed to be very high travel speeds ignoring the feed per revolution rules and applying a more random pattern. This work was done more than 20 years ago, so I do not recall specifics, but I would imagine the structure was somewhat porous. It was, however, strong enough as an independent structure to go through a machining process and perform under load in operation. I am fairly certain the part was made using a wire process as well, although I cannot recall whether it was TWA or LVCW. I imagine you have tried many process changes, but just to be certain and maybe for others interested I believe the following general comments to be accurate when trying to reduce internal stresses:

- Higher powder feed rates (higher non-melted particles and porosity),
- Lower heat input,
- Larger starting powder particle size, and
- Higher velocity may also help, but is dependent on heat input.

Answer 8.2: Have you considered cold spray?

Answer 8.3: I am sure plasma spray with powders or a high-velocity spray would create stresses. I think the solution is to use a normal combustion wire spray system. We have repaired aluminum molds by spraying aluminum with a combustion wire spray gun using oxygen and acetylene and a 1/8 in. (3.2 mm) diam aluminum wire after using a bond coat of our nickel aluminum wire to a thickness of more than 1/8 in. with great success. The bond strength of Ni-Al over an aluminum substrate is more than 3.5 ksi and sufficient enough to bond the subsequent aluminum coating so it could be conventionally machined and used.

Answer 8.4: Try electric arc spraying the aluminum using argon as the atomizing gas.

Question 9

Detonation-Gun. We have some samples of ceramic coatings manufactured by the D-Gun process, they seem far superior than any plasma sprayed coatings. What am I missing, where is the catch? If the D-Gun method produces far superior coatings, why has it not been so popular? If a thermal spray company has rights in the United States, why hasn't it caught up in other parts of world? The only disadvantage with this process is its mobility issues, otherwise it can spray ceramics and hard chrome replacement coatings, which can only be sprayed by HVOF.

Answer 9.1: Which ceramic coatings? Please also define and explain "superior." Without quantitative materials property data (hardness, density, phase stability, adhesive bond strength, dielectric properties, whatever, and under what conditions) I do not think anyone has any basis for making judgments one way or the other.

Answer 9.2: We had received several samples, but specifically it would be Cr_2O_3. The application is for a polyester plant. For starters, the porosity is very low, the substrate temperature is low, a very thin section can be coated without distortion. I was not making any judgment. The "superior" words were used by our client; i.e., the people at the polyester plant. They are using plasma coatings on some parts; we showed them the samples and they passed this judgment. Our basic question is: why has the aircraft industry (blades for turbines) not switched to this? We are planning to buy systems to spraying both cermets and ceramics. The only option at this moment seems to be the D-Gun, as otherwise we would need to buy a plasma system and an HVOF system. I know one process cannot take place of the other, but for the data that I have collected from manufacturers all over the world, the D-Gun process overlaps most of the plasma and HVOF coatings spectrum. My reasons for the previous message were that I wanted to know why this process has not gained popularity such as the HVOF process. Is this process certified by major turbine/jet engine manufactures? What are the technical specs that I am missing?

Answer 9.3: The jet engine industry has not switched to ceramic coatings on turbine blades due to the fact that impact resistance of ceramics under tension is lousy. The centrifugal forces acting on the coating reduce the impact resistance to such a degree that ingestion of dust particles while taxiing or during takeoff/landings would fracture the coating, and the coating particles would wreak havoc on the rest of the engine, particularly those components downstream in the gas path.

Answer 9.4: Every system has advantages and disadvantages. The detonation system can be customized for a specific powder, or production application. The frequency (Hz) can be increased or additional barrels can be added to increase production. The barrels can be made larger, or smaller, to accommodate the size of the parts to be sprayed. The barrel can be made longer, or shorter, to optimize the velocity for a specific coating application.

Advantages:

- The gas supply system completely excludes nitrogen as a protective gas.
- It provides excellent coating quality—the specifications are different for each application.
- You may use lower-cost powders, as powder particle size is not such an issue, due to the long dwell time available (long barrel).
- It has the lowest consumption of gases, cooling water, and energy.
- Variable firing rate—to adjust the deposition rate
- Excellent working reliability and "long-life" fluidic valve design (standard version)
- No moving components, which allows

for an increase in service life, and, a decrease in the cost of operation and maintenance (including downtime)

- Low substrate temperature—allows spraying of a broad range of substrates
- No electrodrive motor
- Economical and reliable operation in an industrial, multishift, production environment

Specifications of a Typical Production Detonation Gun:

- Inner barrel diameter: 24 mm,
- Inlet pressure of fuel: 20 to 30 psi,
- Inlet pressure of oxygen: 30 to 40 psi,
- Consumption of fuel gas: 30 SCFH,
- Consumption of oxygen: 55 SCFH,
- Firing rate: 2 to 100 Hz,
- Exit flame temperature: 3000 °C,
- Substrate temperature: 1500 °C max,
- Particle impact velocity: 800 to 1200 m/s,
- Coating thickness per shot: 5 to 20 μm,
- Oxide content: 0.1%,
- Porosity: 0.1 to 1%,
- Adhesion: 250 MPa,
- Sound level: 140 dB, and
- Materials sprayed: cermets, metals, alloys and ceramics.

Gas Consumption:

The process is intermittent; so, it burns much less gas for a given powder mass. Typical flow rates in the detonation gun (25 to 60 ft^3/min) are about 5 to 10 times less than in an HVOF system. For every minute of spraying, you save quite a lot in gas cost. The gas pressures are much lower in the detonation gun than in an HVOF system: 70 to 210 kPa; in an HVOF system, it is 700 to 1000 kPa. Therefore, the detonation gun can use a regular, low cost gas supply system with standard hoses.

Answer 9.5: The disadvantages of the detonation system are the bulk of the gun (weight and length), the need to move both the part to be sprayed, and the gun (in some applications), the size of the manipulator needed for the gun, and the noise level, which is about 140 dB. With many production applications, these are not issues, as the parts pass by the gun, and are turned, or rotated, as a stationary gun sprays them. Most good acoustic enclosures will handle the 140 dB, which is intermittent, not continuous. Another disadvantage is the initial cost of the detonation system, which is greater than plasma or HVOF. However, the low costs of operation, maintenance, and reduced downtime, soon make up the difference, depending on the amount of use. Further, these systems can be leased, quite reasonably; so that the new business generated by having this equipment will more than pay the out-of-pocket monthly costs. One could possibly acquire a detonation system with no out-of-pocket costs, providing there was sufficient new business to pay for it. Finally, the biggest disadvantage of the detonation system is not having one, if your competing major local spray shop does.

Question 10

Same Nozzle Configuration but Different APS Torches. A thermal spray shop has developed a thermal barrier coating (TBC) process for a part using a Sulzer-Metco 9MB plasma gun using a "GH" nozzle and Ar/H_2 plasma. Should I expect that there would be a difference in the TBC microstructure, and deposition rate, by merely switching over to a Sulzer-Metco 7MB gun, staying of course with the Ar/H_2 plasma, same current, same gas flow rates and a "GH" nozzle?

Answer 10.1: The arc bore geometry is essentially the same when using the "GH" nozzle and should yield the same coating characteristics assuming you are using the same spray booth, spray parameters, gun controller rectifier, and water-cooling system.