JTTEE5 13:176-178
DOI: 10.1361/10599630419706
1059-9630/$19.00 © ASM International

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. To join the discussion group, visit www.asminternational.org/tss and choose Technical Resources *for subscribing information.*

Question 1

Ceramic Densification. Can anyone in the group give me additional information on ceramic densification? How it is applied? I have had a request to apply this on some pump shafts.

Answer 1.1: Depending on the type of ceramics, there is a whole range of methods, such as melt infiltration, chemical vapor infiltration, electrophoretic infiltration, and thermochemical processing (slurry infiltration and conversion).

Answer 1.2: Colloidal suspensions of various ceramic materials (such as silica, alumina, zirconia, and yttria) are available commercially. These can be infiltrated into ceramic coatings, and then heated to drive off water. Further heat treatment can densify the infiltrant.

Answer 1.3: Various colloidal suspensions are also used as inorganic binders for ceramic shell molds for investment casting and can be obtained from investment casting supply houses. Possibly, they can be used as binders in the ceramic slurries fed into spray dryers to make spherical thermal spray powders.

Answer 1.4: Hydrolyzed ethyl silicate can also be used to put silica into pores. Some grades are used as binders to hold zinc particles together to form galvanically sacrificial protective layers on steel. These grades are formulated with chemical additives that help to cure the infiltrant.

Question 2

Differences between WC-17Co and WC-12Co. Our company is coating titanium with a WC-17Co powder using a high-velocity oxyfuel (HVOF) gun. This is a highly tested coating with very specific properties for the use in impact/wear applications. We have been asked to use the same HVOF process using a WC-12Co powder. My questions is: are the coating properties significantly different between the 17% Co and the 12% Co?

Answer 2.1: From testing I have seen variation in coating properties depending on the spray conditions. The properties I am referring to include hardness, ductility, and residual stress. Generally speaking, more cobalt equates to increased ductility, but I have seen data showing comparable wear and fatigue results from either coating. Coating ductility can often equate with better wear performance even though hardness may be reduced slightly. Additionally, ductility affects fatigue performance by increasing the tensile strain required to initiate cracks in the coating.

Question 3

Exothermic Reaction of Tin. We recently started to spray tin (Sn) using twin wire arc spray. Although process-wise everything is okay, we encounter problems with the filtration unit. The filtration unit consists of a cyclone and a baghouse with 16 filters. The airflow rate of the system is 1300 cfm. It seems that after 2 to 3 h of continuous operation, very fine particles of tin pile up in the drums under the baghouse, where they get oxidized. Since oxidation of tin is an exothermic reaction, it produces heat that causes fire. Does anyone know how to eliminate this problem?

Answer 3.1: This could be difficult, but I wonder if there is a way to melt/cast or press the captured tin dust into shapes before it catches fire. For example, to make exhausted dust hit and melt against the inside of an inclined tube furnace and then run out into a crucible or mold. If you or a recycler could then remelt it and skim off the oxide (dross), the recovered tin could be worth something.

Answer 3.2: Pour some water into the drum.

Answer 3.3: Fine metal particulates should not be exposed to moisture in the form of water, as the exposure can be the cause of an exothermic reaction.

Answer 3.4: Would it be possible to add an inert gas (argon) to the drum via a small hose? Then slowly add the gas when spraying. The drum would fill with argon, possibly removing the oxygen from the drum.

Answer 3.5: When the fine particulate is removed from the shielding gas and exposed to air, would this sudden exposure to an oxidizer not be an explosive hazard?

Answer 3.6: 1300 cfm airflow seems low to me, at least for arc spraying. I suppose you could drizzle a small amount of liquid nitrogen into the drums to cool them and keep atmosphere "inert."

Answer 3.7: The exhaust unit manufacturer should be consulted and gain their approval before any attempt is made to modify the existing unit.

Answer 3.8: During electric arc spraying of most materials, you will obtain two main types of powder/dust in the chamber surrounds and extraction system:

- *Type 1:* The larger, heavier stuff originates from the metal spray droplets, when the spray droplets miss the target (~100 μm size) or splashed droplets (~20 μm size) resulting from impact of the main spray and
- *Type 2:* The fluffy, lighter stuff arises from the vaporization of the metal in the arc. When spraying with air, or in air, you can certainly create a lot of this and fill extraction collectors very quickly due to its bulk. Have you tried controlled oxidation of the particles so that they have completely reacted prior to collection?

Answer 3.9: While I do not have a lot of experience with collecting pure tin in dry collectors, I have quite a bit with babbitt, which is 90% Sn. We have experienced constant fires, sometimes in the drums, and worse, sometimes in the collector itself. Fortunately, there have been no explosions or injuries, but we have not found a solution to stop the fires. The end result is, we no longer recommend or sell dry collectors for babbitt spraying. Wet collectors eliminate the fire hazard, but are terribly inefficient for arc sprayed babbitt, as most of the spray particles get through. Using wire flame spray, rather than wire arc spray, will generally produce larger particles, so a wet collector is more efficient. However, whether it would be efficient enough to meet codes would depend on where you are and how much you spray. I do not know whether using wire flame would help the fire problem in a dry collector, but I suspect it would improve matters some.

Answer 3.10: MSDS data sheet states that tin dust will form explosive mixtures with air. How much? The flammable limit in air, percent by volume is, 0.19 oz/ft^3. It does not take much. Have dry chemical handy to put out the fire. I once had the canister on a thermal spray gun ignite to a glowing red from a static discharge. Obviously there was air trapped in the canister.

Answer 3.11: It has been our experience that long duct runs (>200 ft) seem to allow the material to further oxidize and therefore somewhat reduces this risk. Additionally, the buildup of material in the horizontal cartridge type collectors presents a very real and serious problem for all dust applications in that the cartridge inherently retains dust on the top third of the cartridge body. Also, the way that the horizontal units are constructed, there are additional ledges and baffles that retain dust, which increases the potential risk level for fire and/or explosion.

Question 4

Inconsistent Powder Feeding. We are using HVOF to spray a polymer. The feeding of the powder is inconsistent. Please advise why it is happening.

Answer 4.1: Polymers are known for difficult feeding, and if you find your equipment is in good operating condition, you can try warming the powder prior to putting it in the hopper. This seems to improve the flowability of fine sticky powders. I believe the manufacturer of your feeder addresses this problem and offers an optional electric heat wrap for the hopper.

Answer 4.2: Make sure that you have the fine powder wheel in your feeder. If you have the standard wheel it will probably pulsate when it feeds.

Answer 4.3: If you use a fine powder wheel, you must use it for powders that flow well or you will have more powder feeding pulsations with powders that do not flow well. The powder will bridge and then fall, then bridge again and fall again over and over. The fine powder wheel is great for easy flowing powders that flow so well that the entire slot gets striped clear as the leading edge of the slot passes over the powder out hole. The fine wheel keeps the flow at a more consistent feed rate because the speed is close to double from the standard wheel. Also the time duration the slot support bridges are over the powder output hole is shorter due to the higher speeds. Spherical powders usually flow the best, the fine powder wheel is a great tool for controlling these powders feed rate more precisely, with fewer pulsations. This wheel is overlooked all too often. The fact that someone can get their feed speeds up at nearly double or just over double of a standard wheel would provide greater feed control with less noticeable pulsations, using good flowing powders.

Answer 4.4: For everyone out there using a wheel-type of powder feeder, do not use a fine wheel just because the powders are a fine cut. A lot of times (not always) fine powders flow worse than the normal cut powders. Bridging then becomes worse with a fine powder wheel due to the slot being so narrow, making bridging easier and longer lasting. Some pulsations are due to heavy powders settling out in the hose. The bottom of the hose looks like snowdrifts that continue to collect powders behind the drift until the hose blocks off enough to create higher velocities, created from the shrinking ID of the hose area. The higher velocities generated by the smaller ID of the hose will start to erode a clump of powder, and like water over a broken dam, a sudden rush of powder gets feed to the gun. The same thing happens when the rushing powder in a hose creates static voltages strong enough to hold some powders to the sidewalls of the hose. Finally, the velocities will become strong enough to strip a clump of powders away from the magnetic hold on the powders to the hose.

Answer 4.5: The next thing someone can do to reduce the effects of heavy powders settling in the hose due to the powders having too many heavies with velocities that are not high enough to keep the heavies in suspension, is to move to a smaller inside diameter (ID) hose for those powders that are just causing too many problems. This may require a specially made hose to create the proper velocity within the hose. Now here is a word of caution. If the powders are kept in better suspension with a smaller ID hose by causing the velocities to increase, then there may be a problem created by shooting powder delivery through the center of the plasma plume or the flame. In this case you have lost proper powder particle heating and created anode or barrel loading issues. What may have to be done is to install a short 1-2 ft normal ID hose just prior to entering the gun to give those powders a chance to slow down to the proper velocities that were originally developed for injection into the center. The length can be played with to get proper injection without powder settling. Moving over to the powder wheel size, standard wheels version feeders are wonderful equipment. Many of you out there use these style feeders when multiple systems are in the shop and consolidation of feeders takes place. I have found in my service travels that the reason is that these feeders and the wheels doing the actual feeding give the most repetitive feed rates with the fewest breakdowns and the fewest blockage issues. However, the bridges holding the outer ring on are noticeable, consistent pulses; this cannot be avoided and has never been measurable in the coating for as long as I have been a service technician. The bridges are just a noticeable irritant that would be nice to not be there. There is a new wheel out there (I have not seen it) that is designed to have individual holes (no slots) for the powder to fall into and be delivered at a smooth rate (so it has been promised to help reduce the pulsations). I would like to see one run on powders that have a flow problem due to angularity or small sizing. I would envision a greater problem in getting the powders to smoothly fall into the individual hole. For poor flowing powders that are an issue, the tamper assembly is designed to agitate the powders to reduce the pulsations caused from powder bridging. If the powders must be used and they are very stubborn to flow well, even with a tamper installed and in good shape, then an external vibrator may have to be used to help force those powders to slide consistently into the slots or holes. Note: only for the stubborn powders. When you can use the fine powder wheel for nice flowing powders, do so; you will find that the increased wheel speed to maintain the same feed rate is actually a nice thing. The bridge-caused pulsations are less noticeable in the normal feeding due to fact they are now flying over the output hole instead of crawling over the output hole (figuratively speaking). The disadvantage of this wheel is that it does not work for every powder, and you may have to remove it for another job if you cannot leave this powder feeder setup to work with the fine powder wheel due to lack of available feeders.

Answer 4.6: Beyond heating/drying polymer powders to be sprayed, you can also add certain superfine auxiliary powders (more like dusts) in very low concentrations to enhance flow. Examples include various grades of fumed silica and various grades of carbon black from many suppliers. The exact amount needed can be determined by carefully observing polymer + additive blending behavior. For example, start mixing the previously dried polymer in a slowly rotating or double planetary mixer setup so you can watch the powder mix in the bowl or pot. Put in the additive with a spatula or small lab scoop or aluminum foil cup in very small increments (as low as 0.005 wt.%) as the mixer continues to operate. Allow sufficient mixing time to homogenize the contents between additions. You should be able to see the flow improve when enough has been added. If you continue adding beyond this point, the additive may begin to segregate visibly from the polymer. Typically, you will need so little total additive that it will disappear during thermal spray of the blended powder. So its behavior is not degraded by exposure to moisture, the additive should not be exposed to humid air, and leftover additive should be kept in a tightly sealed container. Additives can also be used in the above manner to improve the flow of poorly flowing metal/polymer or ceramic/polymer blends. You will know you have put in too much additive if it or the polymer begins to segregate from the other components.

Answer 4.7: Is the addition of very fine powders for flow enhancement common practice? It seems counterintuitive because fine powders have high surface area, which tend to increase interparticle cohesion. Also, what size are these particles?

Answer 4.8: This not only works for specific powders of this type, but has been used for decades in industry as a production flow control tool. For example, among the fumed silicas, there is a hydrophobic surface-treated grade of Cab-O-Sil. The manufacturer's data sheets should give you an idea of particle size, surface area, and so forth. The fumed silica particles in this case seem to act as little ball bearings to enhance the flow of the larger particles they are attached to. The hydrophobic surface treatment is helpful in extending the useful life of the fumed silica (it keeps the silica from getting like cotton candy), but there are untreated powders, both fumed silica and carbon black, that work, too.

Question 5

Coatings Against Chloride-Type Corrosion. Can anyone suggest a coating to prevent corrosion against exposure to magnesium chloride and water that forms HCl?

Answer 5.1: As far as I know, molybdenum alloys are the best ones against chloride type corrosion. Also, zinc is a good insulator but it is not so hard; however, it is used in parts that are in contact with seawater.

Answer 5.2: At what temperature? How much water is present? Immersed or vapor phase? Both? If above ambient temperature, it will require high nickel alloy with very low/no chromium present. Molybdenum and copper additions would be desirable. Above 150 to 200 °F (65 to 95 °C), this will be difficult if significant water is present.

Question 6

Electrode Lifetime. We have noticed differences in the voltage at the start of the electrode lifetime for different electrodes. Could you advise on how to prevent that?

Answer 6.1: When the same part number electrode is exchanged, and the voltage changes, the difference may be due to changes in electrical resistance across the "gap" between the electrode and the nozzle. Factors/variables that influence this are:

- Relative humidity when the electrode and nozzle were assembled,
- Contamination of the electrode and nozzle surfaces with dielectrics such as skin oils, residues of cleaning solvents (especially those which absorb airborne oils from shop air and leave the residue as they evaporate), or contamination with dirt,
- Dew point of the gases being used when the arc is started,
- Surface finish of the electrode and nozzle (absorption and adsorption of contaminants are affected by surface finish), and
- Actual dimensions of the nozzle and electrode. The diameters and angles, although within a range, still vary within the range or tolerances. An electrode that was manufactured at or near minimum diameter, coupled with a nozzle that was manufactured at maximum inside diameter, will have a greater gap, and therefore will have a greater voltage.

A difference in voltage that occurs when an entirely different configuration of electrode is used is due primarily to the change in the gap between the electrode and the nozzle. Larger gaps require higher voltages to overcome the resistance of the gap, which is proportional to the ionization potential of the gases being used. Inductive (constant current) power supplies will behave somewhat differently than capacitive (constant voltage) power supplies, but generally speaking, Ohm's law will apply to voltages measured between the electrode and nozzle. Vary the resistance, and there will be changes in voltage and current. Usually, acceptable coatings can be obtained by operating the system within the parameter range. The parameters usually take into consideration the variables mentioned. I used to record all the variables I could document and correlate the information with metallography. Conclusion: a stable system, operating within defined parameters produces consistent coating properties and microstructure. Changes in equipment operation should be tracked and correlated to determine when to rebuild or replace components.

Question 7

Cracks in Polymer Coatings. Can anyone explain to me why a polymer coating gets cracks? It is a polymer coating applied on stainless steel substrates via HVOF employing H_2 and O_2 as gases.

Answer 7.1: My first thought would be that the polymer probably shrinks as it cools. Most probably it goes through its glass transition and recrystallizes causing the cracks. R.H. Henne and C. Schitter published a paper in the proceedings of the Eighth National Thermal Spray Conference (1995), which deals with the topic of cracking of polymer coatings on recrystallization and using preheating of the substrate to avoid this: R.H. Henne and C. Schitter, "Plasma Spraying of High Performance Thermoplastics," *1995 Advances in Thermal Spray Science and Technology,* C.C. Berndt and S. Sampath, Ed., ASM International, 1995, pp. 527-31.