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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 and choose Technical Resources *for subscribing information.*

Question 1

Static Electricity in Powder Feed Tube. One of our customers is experiencing a problem with static electricity being generated by a nylon powder feed tube. Basically, the powder is being fed at reasonably high rates (6 kg/h) using argon as a carrier gas. When one disconnects the hose and empties the feeder content, one receives an electrical shock (static), which I think is causing problems to the PTA torch. Has anyone had success with earthing nylon feeder tubes?

Answer 1.1: I have earthed powder feed tubes in the past in order to stop the smaller particles sticking to the inner wall. I just wrapped copper wire around the tube and screwed the end of the wire to the base of the machine.

Question 2

Effect of Chamber Pressure During Vacuum Plasma Spraying. I am a little confused about the effects of changing chamber pressure during vacuum plasma spraying (VPS). I understand that an increase in pressure (e.g., from 50 to 150 mbars) would have effect on particle dwell time. Another doubt: increases in pressure appear to affect the enthalpy of the "flame," but I am unsure of the reasoning behind these effects.

Answer 2.1: Reducing chamber pressure increases the mean free path such that the jet extends significantly. One consequence of this is that spray distances in VPS are typically of the order of 8-10 in. versus 3-4 in. for APS. LPPS thin-film systems use milliTorr pressure levels and spray distance of the order of a meter. The other consequence of lower pressure is that with convergent-divergent nozzles the pressure difference between upstream inside the torch and downstream in the chamber results in a supersonic expansion/flow, and thus higher particle velocities in VPS.

Answer 2.2: The reduced pressure in LPPS or VPS enables the formation of a larger plasma flame size. For discussion purposes:

- If the reduction of pressure is such that it will produce an enlarged flame, but still falling short of reaching the substrate, this tends to increase the particles time of flight through the flame, therefore, the longer the in-flame dwell time of the particle. On the other hand, with decreasing pressure, the mean free path for the molten particles is also increased, tending to make the particles fly through more quickly, therefore, the shorter the in-flame dwell time of the particle. The net result of reducing pressure in this regime will depend on the interplay of this two conflicting factors.

In this case, it is clear that the out-of-flame dwell time is reduced, purely for the reason of increased mean free path of the particle at reduced pressure.

- If the chamber pressure is such that the enlarged plasma flame is already large enough to reach the substrate effectively, from this point, further reduction of the pressure provided the spray distance remains the same. This will mean literally no change in the length of the section of the flame that the particles fly through before hitting the substrate. The in-flame dwell time of the particles is shortened for travel of the same distance, but with increased mean free path (this is an idealized scenario since the spray distance may more likely to be adjusted in this case).

Regarding the effect of pressure on the enthalpy of the plasma:

1. The relatively low-energy density of plasma flame of VPS (versus that of APS) is regarded to be disadvantageous. This means that for a given plasma flame energy (determined by the plasma gas supply rate and powder supply), the energy per unit length in the flame is lower for the larger flame size in VPS. Thus, increasing chamber pressure will result in increased energy density by confining a given energy to a lower dimension.
2. Treating the plasma flame as an ideal gas by approximation, then like any other gases, the enthalpy (H) of the plasma is the sum of its internal energy (U) and the value PV (pressure X volume). U is a constant for a given state of plasma, and a higher chamber PV environment will raise the enthalpy H of the plasma, potentially rendering the plasma to release more heat in form of the change of enthalpy when the plasma interact with other member of the system (powder). Unlike case 1 above, this mechanism explains the increase of the total energy (enthalpy) of the flame at higher chamber pressure (but obviously with limitation bearing in mind that the high heating capacity of plasma comes from mainly the high U of the plasma).

These again are discussions based on simplifications. They are bound to be discrepant from real-life situations, because of the involvement factors beyond those discussed above.

Question 3

Coatings for Food Contact. Would there be people in this group who know which ceramic compositions (i.e., possibly alumina/titania) are approved by the U.S. FDA as being "food grade acceptable"?

Answer 3.1: I do not know off-hand which ceramics are "approved." However, I believe, even if you use an approved material to make a coating you still have to get the local inspector to sign-off on it. There is something about a surface that is in direct food contact that says it has to be capable of being cleaned properly so it will not harbor places for bacteria to grow. For me, this is of particular concern with a thermal spray coating because of interconnected porosity (though it may be small). I suppose an approved sealer would have to be used.

Answer 3.2: The FDA has a mechanism that allows a company to apply for a "nonobjection letter" to allow food contact with materials. Alumina has been used in its alpha form for years in contact with cereal grains. The sprayed version will contain mostly gamma and beta forms, which may or may not be acceptable. Note that the FDA does not "approve" materials for food contact, they only issue the letter I mentioned previously.

Question 4

Arc Spraying of Titanium. Is it possible to spray titanium via wire arc spray?

Answer 4.1: If you use titanium wire in an arc spray process with air as the propellant gas you are going to be operating a flame-thrower. Titanium reacts with both oxygen and nitrogen. You will have a flame so hot that it will melt the gun. The deposit that you spray will be mostly oxides and nitrides. If your intention is to deposit titanium oxide, go ahead, but use the smallest diameter wire you can get and spray it with the highest flow rate of air you can so that you do not burn your gun up immediately. If you spray titanium wire on a titanium substrate, you stand a pretty good chance of starting a titanium fire in which the part you were coating burns and destroys the machinery and tooling to which it is fixed.

Answer 4.2: Another titanium safety issue is the following: as has been noted, oxygen and nitrogen both react with titanium. The only way to avoid nonmetallic inclusions in the coating is to spray using an inert atomizing gas inside a chamber backfilled with inert gas to atmospheric pressure or a low pressure (so-called "vacuum"). However, if the environment for titanium spray is "too inert," the overspray dust that is exhausted from the chamber or that lands inside the chamber will be very reactive with air. Improperly engineered collection systems or ductwork, for example, can suddenly catch fire. Opening the chamber door can be an adventure. Anyone arc spraying titanium or titanium alloy wire needs to consult with the appropriate safety experts to make absolutely sure that the entire spray and collection system and all operating procedures are safe. If it is a turnkey system built with titanium spraying in mind, the system integrator has the responsibility to ensure safety, but the owner/user still has legal responsibility. Operators need thorough safety training and a safe attitude as well.

Answer 4.3: I have witnessed a disastrous attempt to spray titanium wire using arc spray. The atomized titanium reacted vigorously for about a yard beyond the gun nozzle. Instead of the normal straw yellow incandescent spray, there was a brilliant blue white flame. At a distance of 10 ft, I could feel the heat. A new spray booth hood had its paint scorched from the radiant heat, although there was no direct impingement of the spray on to the hood. I have also done metallography on titanium spray deposits. There was a considerable amount of oxide present, and the metallic particles, when etched, revealed that they were mostly alpha titanium due to dissolved oxygen.

Question 5

Coatings for Carbonic Acid/Hydrogen Sulfide Environment. Does anyone have any experience in spraying (and sealing) coatings for corrosion resistance in a carbonic acid/hydrogen sulfide environment? Substrate is carbon steel. The service is at slightly elevated temperatures 50 °C. Preferred method is arc spray, but we are interested in any suggestions/experiences. Conditions stated are similar as encountered in oil field applications.

Answer 5.1: Tungsten carbide, such as, 85-15, 83-17, or cobalt-type alloys have good history and experience. Depending on conditions, however, you may experience corrosion issues with carbon substrate. For example, if sealant is not properly applied or porosity is present, corrosive medium will diffuse through coating resulting in corrosion of substrate, generating hydrogen with blistering being the end result.

Question 6

Roughness Standards for Thermal Spray. Does anyone apply a minimum R_a standard to blasted surfaces prior to spray applications? I realize my question is very generic, and so far as roughness averages will be different depending on various factors such as material type and form prior to blast, media, and pressures used, application method, and spray material.

Answer 6.1: A general standard is R_z 2-3 mils, above 350 R_a μin. This value depends on the factors you mentioned and also on the nominal size of the part. The conversion between R_z and R_a depends on the ISO accuracy class and ISO roughness class defined in your work (see ISO 1302). Also, there are other definitions of roughness besides R_a and R_z, such as R_{max}, R_{3z}, R_{3zmax}. High-velocity methods require less surface roughness too. Perhaps 2-3 mils was at the time more appropriate for arc spray (AWS standard).

Answer 6.2: A R_a of 2-3 mils is a good place to start, but this will vary depending on the substrate material, the application, and the desired bond strength in the application.

Answer 6.3: I have often wondered if R_a is the best technique for measuring surface roughness related to the adherence of a coating to substrate. Roughness R_a is merely the average of peak-to-valley heights, but does not address tortuosity or what I would term the "microroughness." A surface with a sine wave can have high R_a, but does not necessarily provide the small nooks and crannies that could aid the mechanical interlocking of coating to a substrate. Does anyone have suggestions for better techniques to characterize the roughness of surfaces for coating application?

Answer 6.4: The following reference contains an interesting approach to characterizing surface roughness according to your observations. It describes using image analysis and fractal characterization to quantify thermal spray coating surface topography and features contained therein:

G. Montavon, C. Coddet, C.C. Berndt, and S.H. Leigh: "Microstructural Index to Quantify Thermal Spray Deposit Microstructures Using Image Analysis," *J. Thermal Spray Technol., 7*(2), June 1998, pp. 229.