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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. To sign up to the discussion group, visit www.asminternational.org. Go to Affiliate Societies, Thermal Spray Society, and choose Technical Resources *for subscribing information. Sign up for e-mail discussion list or simply send e-mail to join-tss@maillists.com.*

Question 1

Coatings for spheroidal graphite cast iron rolls. We have an application where spheroidal graphite cast iron rolls come in direct contact with hot billet rod (temperature 1250 °C) and are pierced formed and sized in a seamless tube. Due to high-temperature friction, these rolls are wearing out. We are looking for suggestions on coatings that will have good frictional resistance at high temperature and also should not affect the end product surface finish.

Answer 1.1: A fused self-fluxing powder flame sprayed coating will do it.

Question 2

The color of zirconia coatings. Would people in this group know of a manufacturer of partially stabilized zirconium oxide plasma spray powder that turns "gray" when plasma sprayed instead of white, yellow, or cream colored? The purpose would be to color match an as-sprayed TBC coating to one that has been vacuum heat treated, which is gray in color.

Answer 2.1: It turns out that for as-sprayed coating, the appearance is related to powder chemistry, in-flight particle temperature, and application temperature.

Answer 2.2: I do not know if I would classify it as "gray", but if you were using HC Starck's Amperit powders (spray-dried and sintered), the black fleck in the coating may make the TBC look a little duller/grayer than, say, a component sprayed with Metco 204.

Answer 2.3: Depending on the process parameters and spray distance when spraying partially stabilized zirconia, there have been instances when the sprayed coating will exhibit a gray color. This is reduced zirconia. Upon initial heating of the coating O_2 is replenished. I have observed this with both white/yellow powders.

Question 3

Coatings for steam turbine valve components. I have a customer that is looking for an alternative coating for stationary steam turbine valve components (by-pass valve, skirted valve, valve seats, valves and valve stems).

Answer 3.1: For many years the by-pass valve skirts have had an overlay of Stellite 6. On the repair side the cladding is stripped and reclad, and a boride coating applied to the Stellite layer to enhance hardness to 1800 DPH. The valve stems are stripped of the nitride layer and recoated using HVOF chrome carbide-nickel chrome.

Question 4

Measuring coating thickness directly on the workpiece. We are spraying Ni-Al (arc spray) on a P20 plastic injection mold to rectify machining error to thickness of 0.7 mm. After spraying about 12 to 15 passes (manually), we have checked the thickness of the coating using digital thickness gage, which works on both magnetic and eddy-current modes. But to our surprise we are not getting a reading above 350 μm, where the visual thickness on the surrounding areas seems to be more that 1 mm (1000 μm). We request suggestions on how to measure the coating thickness of the workpiece.

Answer 4.1: I would suggest you coat a test piece along with the job for destructive evaluation under optical microscope or SEM. Try to maintain the conditions on the test piece similar to the actual job. The measurements on the test piece should give you a good estimate of the coating thickness on the job.

Question 5

Coatings shafts with ceramic coatings. Here we have got a worn-out stainless steel shaft to be coated using flame spray with a ceramic powder. The total coating thickness required to fill up the worn out area works out to around 600 μm. This process costs more than the cost of new shaft. Hence we would like to know whether we can first fill up the worn-out portion to a thickness of 500 μm with stainless steel 420 by flame spray, and after that a ceramic coating (100 μm thick) with powder flame spray. Please let us know whether after flame spraying (stainless steel 420 wire) the surface has to be blasted, or does it require any premachining, before ceramic coating with powder flame spray.

Answer 5.1: It is possible to coat the shaft first with stainless steel 420 and then spray a 100 μm layer by ceramic. I would advise you to use a Ni-Al bond coat about 100 μm thick before the stainless steel 420 coating. You do not need to grit blast or machine the flame sprayed stainless steel 420 surface for ceramic coating as the as sprayed surface will have an inherent roughness suitable for thermal spraying.

Question 6

Coating polymer substrates with copper. Does anyone have any experience at applying a copper-base material to medium density polyethylene sheet? These are reasonable sized areas, and the intention is to apply the coating with either the arc process or wire flame process; we would need to achieve this preferably without a bond coat.

Answer 6.1: I would suggest looking at using twin wire arc. Maybe with some kind of shroud if the impact of oxidation on conductivity is an issue.

Answer 6.2: I have had no success getting copper to adhere directly to most plastics substrates with either arc spray or flame spray. I believe you will need a bond coat of either zinc or tin, preferably arc sprayed. You should be able to get reasonable adherence by grit blasting the substrate with 80 mesh aluminum oxide, followed by a thin layer (3 to 5 mils) of zinc or tin. You should then be able to apply copper, perhaps as thick as 20 to 30 mils. I would do all spraying at low amperage (50 to 100 amps).

Question 7

Spraying NiCr on ceramics. I have a client that requests 6 mm of NiCr on a ceramic plate (Al_2O_3) with flame or wire spray. Any experience?

Answer 7.1: I would recommend a bond coat of arc sprayed zinc, or perhaps aluminum. But a 6 mm thick coating is far beyond the limits of a wire coating on ceramic. 1 mm would be pushing the envelope.

Question 8

Spraying in internal diameters. We are trying to use a 24 in. thermal spray extension to apply babbitt to the 4 in. inside diameter of an 11 in. long bearing. This is the first time that we have used this extension and are looking for recommendations. The details of our current process are:

- Bearing is mounted in a horizontally rotating chuck.
- Application surface is moving at 170 ft/min.
- Wire: Sulzer Metco 1/8 in. Sprababbitt A.
- The extension sprays the babbitt at approx 45° angle.
- Spray gun and extension are mounted on a positioner that moves the spray tip back and forth through the bore.
- We have tried positioning the tip at 2 and 1 in. from the application surface.

The surface looks very good 2 to 3 in. in from the end of the bearing, but as you go deeper into the bearing, the surface becomes progressively more and more jagged. Final machining shows an excellent surface at the start of the bore with more porosity the deeper you go. We are assuming that this jagged appearance is produced by the 45° spray angle that causes overspray to collect deeper in the bearing bore, but not in an even pattern. The problem was not as bad when the tip was only 1 in. from the surface, but still unacceptable.

Answer 8.1: Years ago, I recall a similar problem that was caused by inadequate exhaust. It was allowing too much metal dust to embed in the coating.

Answer 8.2: You are probably getting a lot of turbulence in the bore, thus creating a lot of dust, which will contaminate the coating the further in you coat. Try placing a couple of compressed air jets to blow the coating area clean (and dust out), as you spray.

Answer 8.3: I agree that the deeper you go, the more "junk" will be in the air to get caught in the spray stream and embed in the coating.

Answer 8.4: We found the best way to minimize dust problems when spraying babbitt internally like this was to always have the bearing mounted vertically on legs, with adequate room to vent at the bottom. We then have an extraction "shroud" mounted above the turntable, around the bearing, to extract the dust. At the top we blow heaps of air down using air coolers.

Answer 8.5: To minimize dusting/overspray from embedding in the coating, ensure that the rotation is such that the surface is rotating down away from the flame. Any overspray and dust collects under the flame instead of falling back into the flame to be reoxidized etc. Occasional use of air jets to clean the debris will assist in keeping the coating quality optimized.

Answer 8.6: When spraying low melt materials, it is very easy to superheat the material. This causes excessively liquid splats, and is very conducive to oxidation. I have solved the problem with cooling air jets that converge at the spray point. I have also solved the problem by making a cooling ring with an annular ring of orifices that cause the cooling jets to converge at the spray point or just beyond. Either one of these will cause rapid cooling and solidification of the metal spray, and blow dust/oxides away from the area being coated. Rotation and spray direction are very important, as others have noted. Additional cooling jets that blow air through the part without disturbing the spray will help. I would suggest allowing gravity to assist the cooling and spray direction.

Question 9

Applying hard chromium plating on a thermal spray coating. Does anyone know if it is possible to apply hard chromium plating after thermal spray coating? If that is possible, what kind of coating could I apply to receive the hard chromium plating?

Answer 9.1: We chrome plate over thermal sprayed coatings all the time. Typically, we use iron chrome aluminum wire as the material of choice, it sprays well and machines to a very nice finish to accept the chrome plating. Note that we do not plate over the coating because we have to but because our customers still think it is better.

Answer 9.2: In my opinion, any iron-base coating will receive hard chromium plating well, but nickel-base coating may not accept the same. Finishing the coating will be a key factor in final finishing of hard chromium.

Answer 9.3: I also have some experience with chrome plating over thermal spray. Plain low-carbon steel also works well and is much more cost efficient than iron chrome aluminum wire. However, you may need to apply a bond coat first.

Question 10

Safety during the thermal spraying of aluminum. One of our customers has requested us to thermal spray a vessel with aluminum using arc spray method. From our research, we know that there is risk of fire (and explosion) if the dust and water concentrations are above a critical limit. Have you ever experienced or witnessed an accident relating with this safety issue? If so, what do you recommend to avoid this occurrence? One of the thermal spray professionals has recommended us to use dust extraction units, but these are very expensive units since the vessel will be in a large chamber. Therefore, we would rather prefer to use powerful fans to supply adequate ventilation; is it possible?

Answer 10.1: Two things you will have to consider, one is the wall thickness of the vessel and second is the contents of the vessel and its properties. Thermal spray being a cold process imparts very little heat on to the base substrate. You could carry out a sample job on a steel plate of the same thickness and make note of the temperature at the back of the coated area. As per our records they are never high enough to create any damage. We do over 20,000 square meters of aluminum coating annually, we have till today not experienced any fire or explosion of any kind taking place. Dust extraction units are not economically viable for aluminizing contracts.

Question 11

Ceramic coatings with enhanced plasticity. I am interested in gathering some ideas and experiences about making a damage tolerant ceramic coating, and what quick and easy semiquantitative tests people have had good luck with. Adding porosity reduces modulus and helps with strain tolerance as with TBCs. This is a good thing, but may not go far enough. The material is to be used as a space filler, so it does not need to be particularly hard or wear resistant, but it does need to resist handling damage, some light impact and some substrate flexing at temperatures up to 1300 to 1400 °F (705 to 760 °C). I know, it sounds like a good application for a metallic coating, but I do need a ceramic.

Answer 11.1: Some researchers have observed that nanostructured ceramic thermal spray coatings exhibit a higher toughness and deformation capabilities when compared to conventional ceramic coatings. As an example you may read the following paper:

- M. Gell, E.H. Jordan, Y.H. Sohn, D. Goberman, L. Shaw, and T.D. Xiao, Development and Implementation of Plasma Sprayed Nanostructured Ceramic Coatings, *Surf. Coat. Technol.,* 2001, **146-147,** p 48-54

In this paper you will see pictures of nano and conventional Al_2O_3-13wt%TiO_2 coatings sprayed via APS on metallic substrates, which were bent after the coating deposition. The conventional coating delaminated but the nano coating remained on the substrate surface. This is a very interesting experience. We also observed high toughness and deformation capabilities on HVOF sprayed nano TiO_2 coatings. We produced nanostructured and conventional TiO_2 coatings by HVOF (DJ2700-hybrid). Both coatings exhibited porosity levels below 1%. We tested the abrasion resistance of these coatings via the ASTM standard G 65. The HVOF sprayed nano TiO_2 exhibited higher wear resistance, but there was another interesting characteristic: the nano TiO_2 coating was more "ductile." When we looked at the wear scars of both coatings via SEM, we noticed that the wear scar of the nano TiO_2 coating was "smeared" and "dulled" like a metal, whereas the wear scar of the conventional TiO_2 coating was "scratchy," like a regular ceramic material. If you want to see these interesting pictures take a look at the following reference:

- R.S. Lima and B.R. Marple, Enhanced Ductility in Thermally Sprayed Titania Coating Synthesized Using a Nanostructured Feedstock, *Mater. Sci. Eng. A,* 2005, **395,** p 269-280

Some of the authors who have been working on these nanostructured ceramic oxide thermal spray coatings seem to agree that the semimolten nanostructured particles embedded in the coating microstructures act as crack arresters, thereby increasing the toughness of the coatings. For more information you may also contact Dr. George Kim (perpetualtech@canada.com) from Perpetual Technologies. I am sure he will have information on the high ductility of these nanostructured ceramic thermal spray coatings.

- **Answer 11.2:** Maybe Ti_3SiC_2. Please check of Professor Michel Barsoum's web page: www.mse.drexel.edu/faculty/barsoum. Additional information about "MAX" phases, downloadable publications, are available on this website. Prof. Barsoum is the expert on these materials. Drexel University holds the patent on the thermal spraying of Ti_3SiC_2.

Question 12

Grit-blasting and threading effects on the bond strength. I am in a debate with a client over bond strength. We use grit blasting as preparation on all our thermal spray coatings. My client is claiming that using the method of thread cutting is just as effective in bond strength. Of course this is not the case as I see it. Are there any case tests using tensile adhesion strength or other that have been done with comparative bond strengths between these two methods?

Answer 12.1: For relatively thick coatings (+80 thousands) used for dimensional restoration on rotating elements, the best surface preparation is proper grit blasting. Even better is to grit blast over a threaded preparation. However, the thread needs to have 45° shoulders with a round groove to minimize stress risers. The advantage is that by using both you produce the correct anchor tooth preparation using grit blasting and you increase the bonded surface area by ~40%.

Answer 12.2: Both grit blasting and threading are mechanical means of enhancing the surface of a profile to aid in coating attachment. Both methods can be carried to extremes to develop high coarseness. The obvious advantage of blasting is that it can be used on any geometry, whereas threading is limited to cylindrical parts. When spraying cylindrical components, not only does bond/adhesive strength play a role, but also so do cohesive and compressive strengths. Regardless of which method is used, remember that the coarser the surface profile, the greater the notch concentration and hence a lowering of the fatigue life of the component.

Question 13

Thermal spray coatings for high heat flux environments. I have a potential customer that highlighted three different families of coatings: NiCrAlY, zirconium oxide, and chrome carbide. The big concern is the thermal stress since the component goes from 800 to 30 °C in a short period of time (a few seconds). Therefore, I am looking for references or experiences regarding these types of coatings. Will they withstand the rapid temperature change?

Answer 13.1: There is a reference from NASA that may help you:

J.A. Nesbitt, Thermal Response of Various Thermal Barrier Coatings in a High Heat Flux Rocket Engine, *Surf. Coat. Technol.,* 1990, **43/44,** p 458-469.

Thermal barrier coatings (ZrO_2-Y_2O_3 top coat and NiCrAlY BCs) were tested in H_2-O_2 rocket engines. The temperature of the coating environment changed from room temperature to 1400 °C in just few seconds. There is also a reference in this paper (Ref 2, Brindley and Nesbitt) that may also help you concerning the durability of TBCs under these high heat flux environments.

Answer 13.2: Our experience with Metco 204NS or equivalent is very good for these conditions.

Question 14

Temperature effect on the hardness of WC-Co and WC-Co-Cr. Does anyone have data on the effect of temperature on the hardness of thermal sprayed WC-Co or WC-Co-Cr? Specifically, at what temperature does the WC start to break down and cause the coating to lose hardness? Does the C go into solution in the Co? What temperature does a significant amount of C go into solution?

Answer 14.1: Typical useful temperature range of WC/Co is up to 900 °F (480 °C). If the coating goes much beyond that, the WC loses stoichiometry and will begin to form WC_2 and complex W + CoC. Much of this can also happen during the spray operation, especially when using plasma. HVOF is the better technique to applying WC/Co.

Answer 14.2: It is not just that simple as 900 °F (480 °C) (though very true number for the WC-Co coating heated in air-filled oven). First of all, it is oxidation reaction that promotes WC decomposition. In inert atmosphere, WC is stable up to 850 °C (1560 °F), and this temperature is higher in carburizing environments (allowing our sintered powder manufacturers and half of powder metallurgy folks stay in business and have their own secrets). Then, there is a "time factor." Finally, there is a "surface-related" activity of WC grains. For instance, nano-WC grains decompose at lower temperatures and much faster than "regular" 1 to 5 μm size carbides. The decomposition of WC in Co or Co-Cr binder does not necessarily mean a decrease of hardness. Intermediate products may have hardness higher than initial WC, while more brittle. Dependent on coating service conditions, this could be beneficial or detrimental for the coating performance.