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TECHNICAL BULLETIN

HVOF SYSTEM NOTES FOR DISTRICT MANAGERS

This technical bulletin expands on the information provided in the HVOF PARAMETER SHEET NOTES and is intended only for Miller Thermal personnel. This is to help Miller Thermal personnel solve a customer's HVOF questions, problems and concerns and is believed to be accurate based on extensive testing done at Miller Thermal.

POWDER INFORMATION

SIZE DISTRIBUTION: Powder particle size, distribution, and manufacturing method needs to be well-defined and closely controlled for spraying a material with any HVOF system. This is especially true for metal powders, which appear to be most sensitive to spray parameters because of their lower melting points and higher thermal conductivies. Information listed here has been divided into metals, carbides, and ceramics.

With any spray parameter selection process, the parameter chosen needs to be based on a nominal powder particle size and distribution. A deviation from this nominal size produces the following results:

1. If the largest powder particles in a nominal powder lot are too large, they will reduce the coating deposit efficiency. This is due to inadequate heating of the particles, resulting in the particles ricocheting off the substrate due to their inelasticity.

2. Slightly smaller particles which are still larger than the mean particle size will have enough plasticity to deform on the substrate but not totally flatten. These result in globular or unmelted particles which may pullout of the deposited coating during the grinding or machining operations, leaving an undesirable void on the surface.

3. Powder particles that are too small may result in buildup and/or clogging of the combustion nozzle. Powder distribution is an effectual aspect and needs to be considered when evaluating powders for HVOF systems.

Powder manufacturing methods are very important. This is especially true for metal powders where the gas atomized particles usually provide more uniform microstructures and higher powder feedrates than water atomized particles which may cause gun feeding problems. Mechanically-bonded composite powders (i.e., AI-1037 and AI-1047) exhibit some nonuniformity in the coating microstructure. Nonuniformity depends on particle size, distribution and the melting points of materials that make up the composite structure.

APPROXIMATE MELTING POINT: The amount of thermal energy required to melt the powder correctly during the combustion process is directly related to the thermophysical behavior of the material.

NOMINAL COATING CHARACTERISTICS

DEPOSIT EFFICIENCY: When using identical spray parameters, deposit efficiency is related to particle size, distribution and manufacturing method.

SUPERFICIAL HARDNESS/MICROHARDNESS: Superficial hardness is the bulk hardness of the material taking porosity into account. Microhardness is the hardness of the individual microstructural constituents in the coating. The difference between the values appears to be a general measure of the porosity levels in the coating.

SURFACE FINISH AS SPRAYED: Surface finish is mainly an indication of powder particle size, with larger particles producing a rougher surface finish. Spray parameters also affect the as-sprayed surface finish with a higher oxygen-to-fuel ratio producing a rougher surface with metals.

TENSILE STRENGTH: Tensile strengths provide limited information regarding HVOF coatings because the coatings usually have a higher adhesive (coating to substrate) and cohesive strength (particle to particle) than the adhesives used to bond the test sample.

POROSITY: Powder feedrates have a direct effect on porosity levels, with higher feedrates generally producing higher porosity levels, particularly with carbide coatings.

GLOBULAR PARTICLES: Globular particles can be an indication of incorrect powder particle size, incorrect fuel or oxygen flows and/or ratios, incorrect powder manufacturing processes, or powder feedrates that are too high.

OXIDES: For metal coatings, oxides are usually present as oxide stringers or oxide clusters. Both forms of oxide represent a high oxygen-to-fuel ratio or powder particles that are too small. Oxides are sometimes present in stratified layers caused by the spray distance being too close or the gun traverse speed being too low.

MAXIMUM SERVICE TEMPERATURE: The maximum service temperature for a particular coating in a specific environment may be lower than the value specified in the data sheet. This temperature value is a reference point only.

MAXIMUM COATING THICKNESS: Maximum coating thickness depends on numerous factors, including the coefficient of thermal expansion of the base metal and coating material. Some other critical parameters include spray distance, thermal energy, and method and extent of part cooling.

SPRAY PARAMETERS

HARDWARE: The only gun hardware options pertain to the nozzle type. Generally, when using the same gas flows to spray a given powder, the 0 mm nozzle produces a coating with the least amount of oxides; the 22 mm nozzle produces a coating with the most oxides.

The 0 mm nozzle is suggested when spraying metal powders; since oxides are not a significant concern with carbides and are required for most ceramics, a 19 or 22 mm nozzle is suggested when spraying these materials. Note that the 0 mm nozzle will not work using hydrogen as the run fuel gas.

CONSOLE PRESSURE: The console supply pressures are fixed values for each gas because the console flowmeter readings are based on the console supply pressures. Note that for spraying some metal powders, a lower carrier supply pressure may be required to eliminate spitting. Do not use less than 60 psi or less than 10 scfh at 100 psi.

IGNITION FLOW RATE: The ignition flow rates should be adjusted until the gun can be easily lit with the console operating in either the manual or automatic modes. If the carrier gas ignition flow is too high, the flame will blow out away from the gun. Hydrogen is the only known fuel gas for starting this system. This is because upon lighting the gun, the flame can travel back into the combustion nozzle and burn just in front of the gas mixing block.

- CAUTION: EXCESSIVE IGNITION BURN TIME WILL DAMAGE THE GAS MIXING CHAMBER INSIDE THE GUN. ONCE GUN IS LIT, IMMEDIATELY SWITCH CONSOLE TO NEXT GAS OPERATING MODE. FOR CONSOLE IN MANUAL MODE, PRESS THE RAMP BUTTONS. FOR CONSOLE IN AUTOMATIC MODE, PRESS THE RUN BUTTON. TOTAL IGNITION RUN TIME SHOULD PROBABLY BE LESS THAN THREE SECONDS.

RAMP FLOW RATES: The ramp gas flow rates should be adjusted so the flame can be easily transitioned from the ignition mode to the run flow mode. If the run gas flows are low, the ramp gas flows could be the same as the run gas flows. If the ramp gas flows are too high, the flame may be extinguished when the gun is switched from ignition to run when console is in the automatic mode.

RUN FLOW RATES: The run gas flow rates are the gas flows that currently produce the most desirable coating microstructures. From the many tests conducted using the gun with standard Miller Thermal flashback arrestors, Miller Thermal recommends the following oxygen to fuel ratios:

1. For producing low-oxide, dense metal coatings, the oxygen to propane should be approximately 4.0; propylene, 3.3; hydrogen, .27-.30, and acetylene is generally not used. Note that this relationship does not hold for molybdenum and nickel-chromium-boron powders, which require oxygen to fuel ratios close to combustion stiochiometry value (see below table).

2. For producing tungsten and chromium carbide coatings with hardness levels as detailed in the HVOF bulletins, the oxygen to propane should be approximately 4.5-5.0; propylene, 4.0; hydrogen, .40, and acetylene is generally not used.

3. For hard, dense ceramic coatings, the oxygen to propane is usually not recommended; propylene, 4.5 to 5.0; hydrogen, .35 to .40; acetylene, 1.81 to 2.25.

When clogging occurs in the combustion chamber, modify the fuel and oxygen flows by keeping the oxygen-to-fuel ratio constant and reducing the total oxygen and fuel flow accordingly. The hotter the flame, the closer the clogging locates to the face of the gas mixing chamber inside the gun on the nozzle wall.

The following data is known about the Miller Thermal HVOF system:

1. Roughly 25% of the total thermal energy heats the gun cooling water.

2. Roughly 74% of the total thermal energy heats the surrounding air and the substrate.

3. About 1% of the total thermal energy heats the powder particles.

The following gas thermophysical data is known:

Fuel Gas	Max flame temp. (F)	Oxygen/Fuel Ratio for max temperature	Oxygen/Fuel Ratio for stiochiometry
Acetylene	5720	1.5	2.5
Propylene	5245	3.7	4.5
Propane	5122	4.3	5.0

This data is applicable for unrestricted flames only; no information is known to exist on restricted type flames. Note that the oxygen to fuel ratios referenced for maximum flame temperature do not produce the "optimum" coating characteristics.

The carrier gas flow/pressure must be high enough to carry the powder from the hopper to the combustion chamber area of the gun without any progressive buildup in the powder hose. This buildup condition is noticeable after the gun is extinguished and the powder flow through the gun is at the same or higher flow rate compared to the console run conditions with the gun lit. The denser the powder, the higher the carrier gas flow setting required to transport it. Also, the carrier gas flow must be sufficient to prevent the combustion flame from burning back through the rear of the gun and into the powder hose, causing the hose to melt. For metals, if the carrier gas flows/pressure are too high, the powder may spit after 2+ minutes of running the gun.

The particle density can be used to establish the powder feedrate; the maximum powder feedrate for this gun is six cubic centimeters per minute. Using feedrates less than this value seems to produce a denser coating, particularly with carbide powders. Using a feedrate above six cc/min. results in spitting and clogging in the combustion nozzle. The spitting will form globular particles in the coating microstructure and can be pulled out during machining and grinding operations, leaving an undesirable void on the surface.

MISCELLANEOUS: The standoff distance, combined with part cooling, greatly influences the tendency toward oxidation of the coating surface particularly with metal coatings. Carbide and ceramic coatings tend to crack or delaminate if standoff distance or part cooling is too low. Methods imparting cooling to the coating surface are better than those methods cooling from the base metal surface.

Deposition rate per pass is a suggested range of coating thickness buildup per pass that is affected by coating and substrate thermophysical properties, part cooling and part manipulation. The more dissimilar the thermophysical properties between coating and substrate, particularly coefficient of thermal expansion, thermal conductivity and toughness throughout the combustion gas temperature spectrum, the lower the deposition rate per pass. The more cooling capacity and uniform powder deposition process used, the higher the deposition rate which can be achieved prior to exceeding the maximum permissible coating stress.

Gun water flow and inlet temperature are generally not important factors when producing HVOF coatings using this system.

COMPARISON OF MILLER THERMAL AND COMPETITION HVOF SYSTEMS

The Miller Thermal HVOF and Jet Kote® systems are similar when comparing maximum powder feedrates and most coating properties. In terms of system operating costs, the Miller Thermal system does not require high water inlet temperatures for producing typical coating microstructures, and does not require substantial oxygen and fuel consumption. The Jet Kote® uses more total fuel and oxygen gas to produce the same coating as the Miller Thermal system, with some parameters requiring greater than 75% more total gas flow. Also, the Miller Thermal HVOF gun lacks high consumption components.

The Miller Thermal nozzle life is undetermined but should easily last a few hundred hours under normal usage; however, the Miller Thermal nozzle is several times more expensive than the Jet Kote®, which lasts only a small fraction of the time. Also, the spray distance is usually between 6-9 inches with the Jet Kote® gun compared to 9-11 inches with the Miller Thermal gun, resulting in higher substrate heating for the Jet Kote® substrates.

The Diamond Jet® system has lower equipment and operating costs compared with the Miller Thermal system because the gun is air cooled and does not require a heat exchanger. Still, there are several drawbacks. The system does not supply the same feedrates as the Miller Thermal system. Diamond Jet® literature states 45 gpm for tungsten carbide materials compared to 75 gpm for the Miller Thermal system. Also the coating properties appear to be lower than the Miller Thermal system as evidenced by the lower superficial and microhardness values provided in the Metco literature. Also the spray distance is usually 6-8 inches and more of the heat input from the flame is heating the base material as compared to the Miller Thermal system.

A water cooled option has been recently introduced for the Diamond Jet® gun but nothing is known of its operation, at this writing.

Little is known of the Continuous Detonation System®, CDS® marketed by Sulzer Plasma Technik.