

Diagnostics Correlation Study of 8%-YSZ Deposited by F4-MB APS Torch

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Background:

Modern gas turbine hot sections need to be protected from elevated temperature and damaging environments. This protection starts as a typically two layer coating system, the base layer or bond coat (BC) acts as a corrosion barrier and a kind of buffer for the thermal mismatch between the base material and the second top thermally protective layer or Thermal Barrier Coating (TBC). The BC is normally a metallic MCrAlY type coating where M is Ni and/or Co. The TBC is a high temperature stable ceramic material; alumina and 5-8at% Yttria Stabilized Zirconia (YSZ) coatings are used on most components. Both types of coating BC and TBC's are commonly deposited by thermal spray operations from a fine starting powder. Bond coats are commonly deposited by a process called high velocity oxy-fuel (HVOF), and TBC's are deposited by plasma thermal spray.

This project focuses on one thermal spray process, Atmospheric Plasma Spraying (APS). With the APS process an inert gas mixture is flowed through an accelerating voltage which generates a high temperature plasma under atmospheric conditions. The powder, fluidized by a carrier gas, is then injected onto the plasma stream where it is accelerated and heated to a molten or semi-molten state. These powder droplets then impact a target substrate flattening out and solidifying. Over repeated passes a thick coating is deposited. The microstructure of this deposited coating is critical to the coatings strength, thermal and corrosion protection, and adhesion.

The powder being used in this project is zirconia stabilized by 8at% yttria. The reason for this is to eliminate the phase transformation of the high temperature tetragonal to monoclinic zirconia phase on cooling; this phase change is characterized by a large volumetric change which fails the coating. Also the coatings density is important, the higher the density the longer the coating lasts. By altering APS processing parameters like: primary gas and secondary gas flow rates, applied current and powder feed rate among others, drastically change the coatings microstructure. Correlating changes in processing parameters with final microstructure is difficult. When spraying a thermal coating two relatively easy and repeatable measures of coating quality are used. These parameters are powder temperature and velocity. The measurement of powder particles temperature and velocity can be conducted by various techniques. As a result diagnostic sensors have been commercially developed for use in the spray processes. The purpose of this project is to correlate two such commercial diagnostic sensors by using the same APS spray conditions.

Sensor overview:

Two commercially available sensors were used, the first sensor was the SprayWatch® (Oseir Ltd) and the second sensor was Tecnar’s Accuraspray®. Both sensors measure average particle temperature and velocity. To measure these values accurately the sensors rely on an assumption, this is, that the spray plume is at the same pre-ordained location each time a measurement is taken. For each sensor this location is indicated by the manufacturer. The temperature in both sensors is measure by two color pyrometry techniques.

Two-color pyrometry is a non-contact method of determining temperature. By using a gray body assumption of Planck’s relation call the Wien radiation relation at two different wavelengths, λ , and temperature can be found independent of emissivity of the particle as long as the emissivity is the same ($\epsilon_1=\epsilon_2$) at both wavelengths, Eqn 1 [1].

$$T = \frac{\lambda_2 - \lambda_1}{\lambda_2 \lambda_1 \left(5 \ln \frac{\lambda_2}{\lambda_1} - \ln \frac{N_1}{N_2} + \ln \frac{\epsilon_1}{\epsilon_2} \right)} \tag{Eqn 1}$$

To measure particle velocities the sensors differ. The SprayWatch uses a single CCD camera with a known shutter speed, as the particle exposes the screen it forms a small streak based on the assumed spray distance and the length of the streak the velocity is determined. The accuracy of this measurement is $\pm 10\text{m/s}$.

The Accuraspray use two optical fibers that are separated by a small distance. These fibers sample the target plume, due to the separation of the fibers each signal is slightly offset giving a time shift which is used to calculate velocity, this method is accurate to $\pm 12\text{m/s}$, figure 1. Also each fiber is filtered giving the two wavelengths for the temperature measurement.

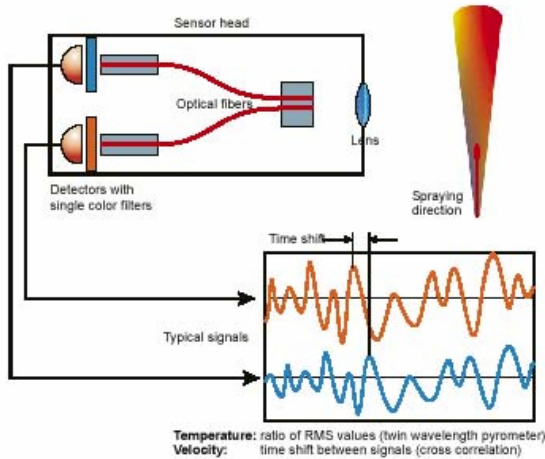


Figure 1 - Accuraspray sensor scheme

It is also important to understand the measuring volume for each sensor. The SprayWatch sensor measures a 20mmx16mmx14mm volume 200mm from the face of

the sensor, figure 2. The Accuraspray measures a 3mm diameter x25mm at 200mm from the face of the sensor, Figure 3.

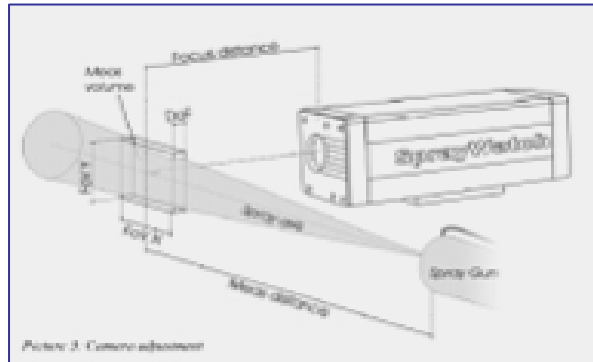


Figure 2 - SprayWatch sensor alignment diagram

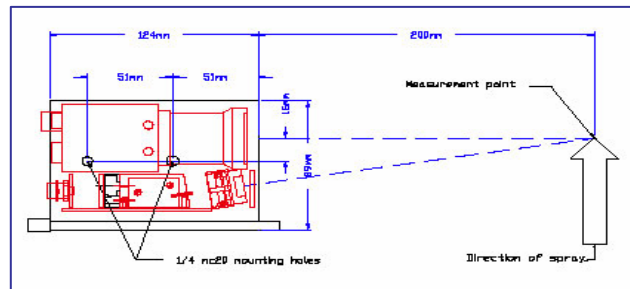


Figure 3 - Accuraspray sensor alignment diagram

Experimental setup:

An APS spray cell was used in this project outfitted with the SprayWatch and the Accuraspray sensors, figure 4. Due to time constants on the project only sensor data was collect. All experiments used the Sulzer Metco F4-MB® torch, figure 5, spraying commercially available 204-NS 8at% YSZ with a 125 μ m cut. The torch was setup with a 6mm nozzle with 0° powder injection, measured from the normal to spray axis. Gases used where argon for primary and hydrogen for secondary gas. Measurements where taken with a standoff of 100mm from the torch face.



Figure 4 – spray cell and sensor setup

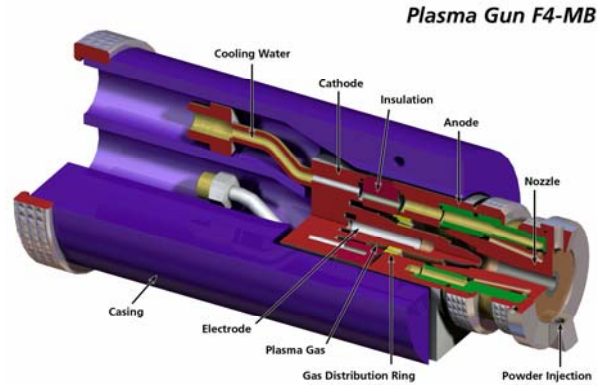


Figure 5 - F4-MB torch schematic

Eight test run configurations were conducted by varying current and primary and secondary gas flow rates keeping all other parameters constant. The gases were varied between low and high values 50 and 100 SCFH for primary and 5 and 20 SCFH for secondary at two current settings 400 and 600 amps, these eight configurations are seen in table 1. For each of the test runs three separate samples were taken at the same position then averaged together to give the final measurement values.

| Table 1 | Current | Primary SCFH | Secondary SCFH |
|---------|---------|--------------|----------------|
| | | Ar | H2 |
| Run 1 | 400 | 50 | 5 |
| Run 2 | 400 | 100 | 5 |
| Run 3 | 400 | 50 | 20 |
| Run 4 | 400 | 100 | 20 |
| Run 5 | 600 | 50 | 5 |
| Run 6 | 600 | 100 | 5 |
| Run 7 | 600 | 50 | 20 |
| Run 8 | 600 | 100 | 20 |

Results:

Temperature:

The plot of the temperature readings, figure 6, for the sensors shows a very similar trend overall, by increasing the primary, secondary or current the temperature of the spray increases with the largest increase when both primary and secondary gas flows are increased in runs 4 and 8. By comparing the measurements between the sensors one sees a linear correlation, figure 7.

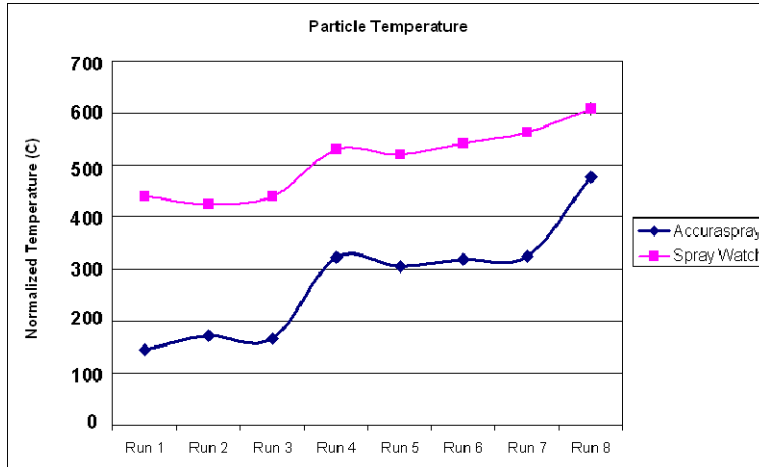


Figure 6 - Temperature plot

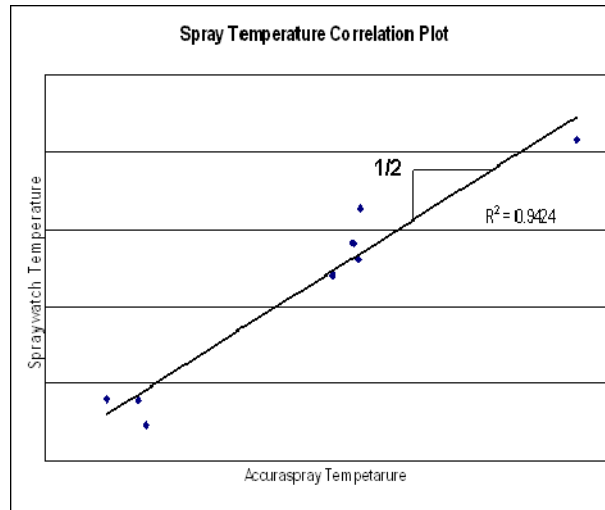


Figure 7 - temperature correlation plot

Velocity:

The velocity plot, figure 8, also shows the same trend between sensors. By comparing the plots one sees that the velocity is dependent on the primary gas flow. Runs 3 and 7 show this trend, since the for these runs the secondary gas flow is increased but one sees a depression of the velocity below the 400 and 600 amp base lines, runs 1 and 5, respectively. The correlation plot for velocity, figure 9, also shows a linear trend.

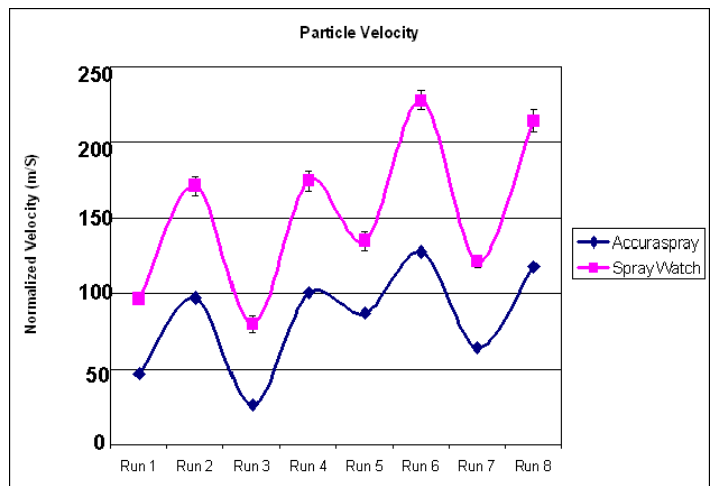


Figure 8 - velocity plot

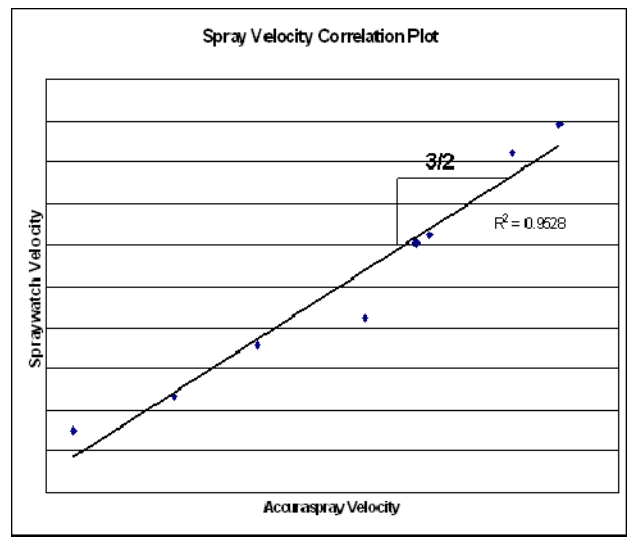


Figure 9 - velocity correlation plot

Discussion:

As discussed before accurate positioning of the torch to the sensor head is critical to accurate diagnostics measurements. Slight variations in the alignment were observed to cause large fluctuations in the measurement during final alignment of the plume to the sensors. As seen in the results there was a measured discrepancy between the sensors. One possible reason is the different measurement volumes of the sensors, since the SprayWatch system samples more of the plume than the Accuraspray this may cause the higher measured values. Though the trends of both the temperature and velocity are the same only offset. This is also confirmed by the correlation plots, showing that the discrepancy between sensors for each runs measurement is a constant, $1/2$ for the temperature and $3/2$ for the velocity. This leads one to reason that the discrepancies in the sensors could be an artifact of the sensor alignment or some other internal calibration of the sensor.

Future work:

Originally planned but not completed due to time constraints, a sensitivity study to the torch position changes and internal sensor calibrations still needs to be conducted to determine the root of the observed discrepancy.

References:

- [1] M.A. Khan, C. Allemand, and T.W. Eagar, "Non-Contact True Temperature Measurements for Process Diagnostics", Proc. of materials research symposium on process diagnostics: Materials, Combustion, Fusion, 117, 119, 1988.