Cold Spray

Literature Review
Week - 1
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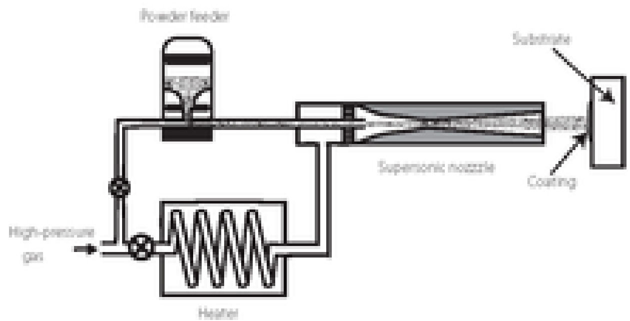
1 Introduction

This report postulates a short description of the cold spray mechanism, the science behind the mechanism, particle impact, and bonding condition that takes place in the process. The method of cold spray was a successor for the thermal spray which was considered to have a low-quality finish and formation of oxidation level over the material. The Thermal spray is provided by melting the spray particles in a chamber and deposited onto the substrate. While in the case of Cold spray, the spray particles are directed with high velocity to the substrate to make the coating by plastic deformation of the particles. The invention of the cold spray method goes back to the 20th century when it was developed and patented by Thurston. The usage of the cold spray method made it possible to many applications which provide a better outcome for the product.

2 Cold Spray

As we discussed, cold spray is an emerging technology where the main application lies in the industry of Aerospace, Automotive, Glass, and electrical engineering. The cold spray technique is performed by converting the kinetic energy of high-velocity particles into high thermal and mechanical energy to adhere to the surface of the substrate. The cold spray technique uses some initial conditions to provide a better impact on the particles which are discussed below. The equipment setup of cold spray consists of a gas heater, where the highly pressurized gas is fed and taken out of the chamber, a powder feeder in which the powdered particles can be poured into the upcoming gas typically nitrogen or helium (inert gas), and a de Laval Nozzle which is used to accelerate the particles with a high velocity between 200 – 1200 m/s. Since the gas temperature can be maintained around 320-degree, the particle temperature when it exits the diverging section of the nozzle is maintained over 330-degree which is an effect of particle-preheating to obtain a better particle impact temperature and adhesion.
The powder particle's impact on the surface of the substrate will undergo extreme plastic deformation due to their ballistic impact, leading to a bonding mechanism known as "Adiabatic Shear Instability". There is a sweet spot where the bonding mechanism takes place, below and above the limit produces no adhesion and cracks in the substrate. Several factors affect the

particle impact on the surface of the substrate, but the important factor which comes into play is the nozzle design. The nozzle part in the equipment plays a major factor in the velocity of the impact particles. A detailed review of the nozzle used in the experiments is discussed in the below section.



3 Nozzle

Two types of nozzle geometry can be used for the cold spray model. The most commonly used type is the bell-shaped nozzle in which the cross-sectional area of the diverging section of the nozzle is greater than the converging section. It has a high angle expansion section (20 to 50 degrees) right behind the nozzle throat, this is followed by a gradual reversal of nozzle contour slope so that at the nozzle exit the divergence angle is small, usually less than a 10-degree half-angle. There are some non-axial components to momentum associated with the geometry, in which the momentum vector forms an angle between the axis of the nozzle and the gas flow which results in lowering of thrust. The experiments conducted on the cold spray show that a bell-shaped nozzle that provides velocity distribution at the exit is significantly more homogeneous than a trumpet-shaped nozzle. But this kind of differentiation of nozzle is only suitable for a certain type of process gases. In the practice process gas such as nitrogen or helium is used. The experimental advantage shows that copper particles of size 25µm will have an impact velocity of 525 m/s, which is 75m/s faster than the trumpet-shaped nozzle. Raising the temperature of the process gas will increase particle velocity. The experiment results show that by raising the pressure and temperature of the process gas, the velocity of a copper particle of size 25µm has increased from 490m/s to 620m/s and the particle temperature has increased from 70-degree to 330-degree, which provide better particle surface adhesion.

4 Particle Impact

The particle impact condition is based on their thermal history and thermal inertia, in which the particle of smaller size will heat up quickly while entering the converging section, whereas releasing a considerable amount of heat while passing through the diverging section results in the decrease in the particle impact temperature. The experiment results show that particle size of 5µm, injected at the smallest cross-section of the nozzle cools down while traveling through diverging sections because of their low thermal inertia. On the other hand, the particle size of 50µm heated up slightly on the smallest cross-section and because of their large size, they manage to pass the diverging section with considerable thermal energy to make an impact on the substrate. This can be rectified by pre-heating the particle before they are injected.

There are some factors which should be taken into consideration for better flow and impact conditions,

1. **Gas Velocity are determined by:**

- Gas temperature.
- Expansion ratio of spray nozzle.
- Gas type.

2. **Particle impact velocity depends on:**

- Acceleration in the surrounding gas jet.
- Gas velocity.
- Drag force by gas density (or) pressure.
- Nozzle length.
- powder mass.

3. **Particle temperature upon impact depends on:**

- Gas temperature.
- Gas density (or) pressure.

- Heat capacity of gas.
- Nozzle design.
- Heat capacity of particles.

5 Particle Bonding

The bonding of the particle onto the surface of the substrate is based on the critical velocity of the particle, in which there is a sweet spot between the critical and erosion velocity of the particles. Every particle has its critical velocity. For material with ideal ductility at a certain velocity the deposition occurs. By increasing this velocity, the deposition efficiency has increased, but further increase in velocity decreases the deposition efficiency of the particle because of the erosion effect of the particle on the substrate. This phenomenon is known as large-scale impact dynamics.

- Lower particle velocity – abrasion of substrate by fatigue fracture.
- Exceeding critical velocity – thermo-mechanical conditions are reached under which material can be deposited.
- Above erosion velocity – material is removed from the substrate by hydrodynamic effect.

The bonding is due to the plastic deformation of particles on the substrate. The experiment shows that around 50ns is taken for a particle to bond with the substrate in such a way that produced heat cannot be dissipated leading to highly localized Adiabatic Shear Instabilities (ASI).

6 Conclusion

This report gives an introductory idea of cold spray, the mechanism, and the bonding conditions. The experiment conducted in different papers shows that particle pre-heating provides better deposition efficiency and maintaining the temperature and pressure of nozzle and gas can helps in maintaining the velocity of the coating particle.