Considering Cold Spray for Additive Manufacturing

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Thermal spray encompasses a variety of coating processes that apply metals, polymers, ceramics, cermets, and other materials onto metallic, polymeric, composite, and ceramic substrates. One of these processes is cold spray, which propels feedstock material against a substrate with enough kinetic energy to produce a dense coating or freeform at relatively low temperatures.

Cold spray is beneficial in applications that use heat-sensitive substrate materials or those with difficult-to-reach spray areas. One example involves spraying inside small-diameter, heat-sensitive tubes or bores to provide corrosion resistance. Cold spray produces deposits that are oxide-free and fully dense with acceptable mechanical properties. The process requires heating of a pressurized carrier gas (typically nitrogen or air) that is passed through a "DeLaval" convergent-divergent nozzle. The divergent section of the nozzle creates a supersonic gas jet as the carrier gas expands toward the nozzle exit. The spray material (in powder form) is injected into the gas jet either upstream or downstream of the nozzle throat.

Depending on the process temperature, each material requires a specific minimum particle velocity in order to successfully form a well bonded and dense deposit. The latter depends on the material's ability to plastically deform upon impact. Therefore, the less ductile the spray material, the more particle velocity required to produce bonding. In practice, a cold-spray-grade powder mix must contain, at least, one material that can easily deform upon impact with the substrate surface.

Commercial cold spray systems, including upstream and downstream injection systems, have been available for more than a decade. Cold spray was primarily designed for use in applications that are extremely sensitive to high process temperatures. Examples include:

- Dimensional restoration of bearing surfaces of cast aluminum and cast iron for automotive, marine, locomotive, and earthmoving equipment
- Manufacturing of electrically conductive buses on the delicate surface of coated conductive glass for heated glass applications
- Deposition of pure aluminum inside semiconductor processing chambers to reduce contamination
- Repair of corroded surfaces in magnesium components for commercial and military aircraft
- Restoration of corrosion damage in nuclear reactor vessels

In downstream injection cold spray, the spray powder is injected into the nozzle tube downstream of the throat. The major benefits of this approach include the ability to design and build smaller guns for greater accessibility and maneuverability and the ability to manufacture practical, low cost, durable engineered consumables that experience minimal erosion from the spray materials (Fig. 1).

In order to spray inside hard-to-access constrained spaces, some manufacturers developed special nozzle assemblies as seen in Fig. 2. Given the required short standoff distance (8-15 mm) and the low temperature of the process, cold spray is considered superior to other thermal processes with regard to surgically depositing material onto hard-to-reach heat-sensitive surfaces, and without the need for masking.

As manufacturing processes move forward, cold spray is becoming more attractive as an enabling technology for 3D printing or additive manufacturing. Traditional manufacturing relies on subtractive manufacturing techniques,

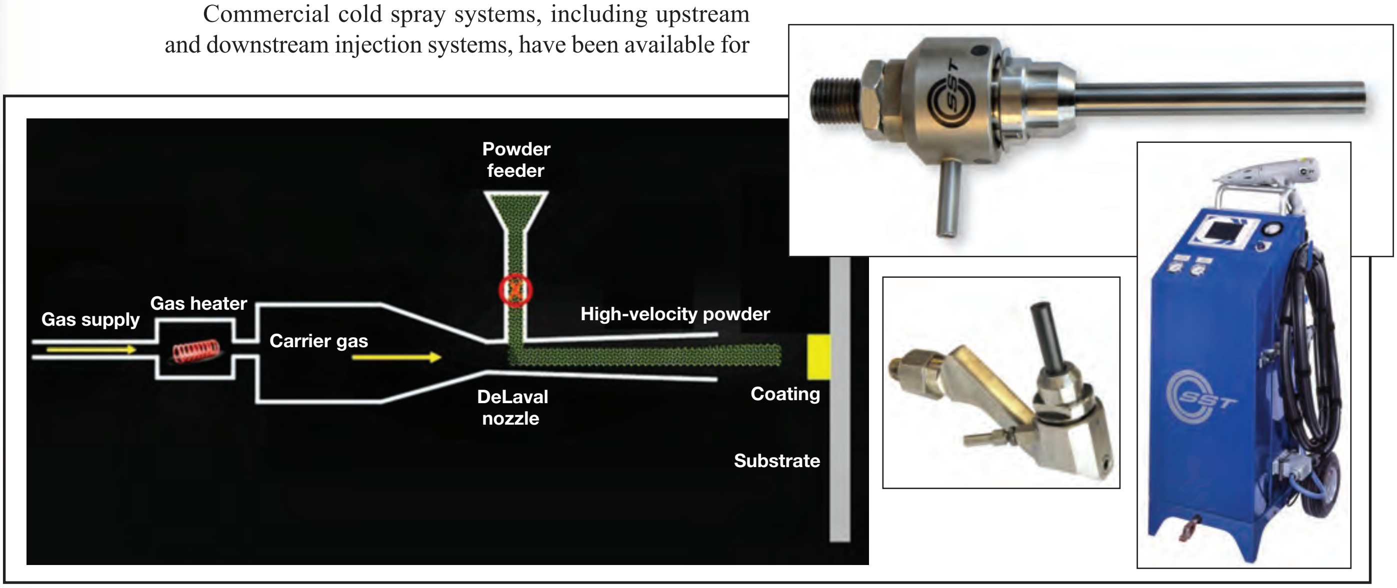

Fig. 1 — *Downstream injection system SST Series P with manual gun, showing modular easy-access nozzles. All images courtesy of CenterLine (Windsor) Ltd.*

**Member of ASM International and ASM Thermal Spray Society* and involves systematic removal of material from bulk shapes by cutting or drilling to arrive at a final shape. Additive manufacturing, on the other hand, builds shapes by precisely adding and consolidating layers of materials following a 3D digital model[1]. Depending on the nature of the materials involved (e.g., polymers vs. metals) as well as the application, a wide range of consolidation techniques may be used including photopolymerization, material jetting, binder jetting, extrusion, powder bed fusion (laser processing[3-5]), direct energy deposition (welding[2] and laser processing[3-5]).

Currently, additive manufacturing is mostly used to create functional prototypes or components made of polymeric materials because consolidation techniques for polymers are economical and readily available. At the other end of the spectrum, additive manufacturing of functional metallic parts has been limited by the metallurgical challenges associated with consolidating metals and other elevated temperature engineering materials of interest. Today, selected metals, such as titanium, cobalt, chromium, and nickel-base alloys, can be used to create high-value custom engineered components for aviation[6] and medical uses.

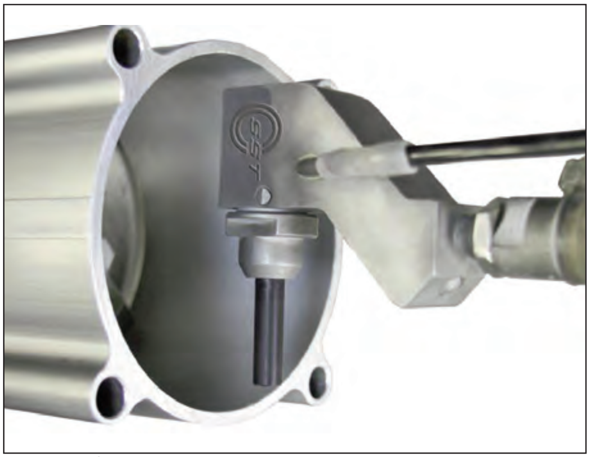

Fig. 2 — *Special right-angle nozzle assembly developed to access hard-to-reach surfaces.*

The geometrical quality of a complex 3D shape is dictated by spot size resolution (the smaller the better), which is why laser beams on powder beads are the preferred method for producing intricate geometries made of special alloys. Currently, the smallest spot size for cold spray deposition is about 4.0 mm, which is sufficient for 3D dimensional restoration of an assortment of metallic components in the world of remanufacturing or rapid prototyping (Fig. 3). However, a much smaller cold spray footprint would be required to produce a highly finished shape. Manufacturers are already work-

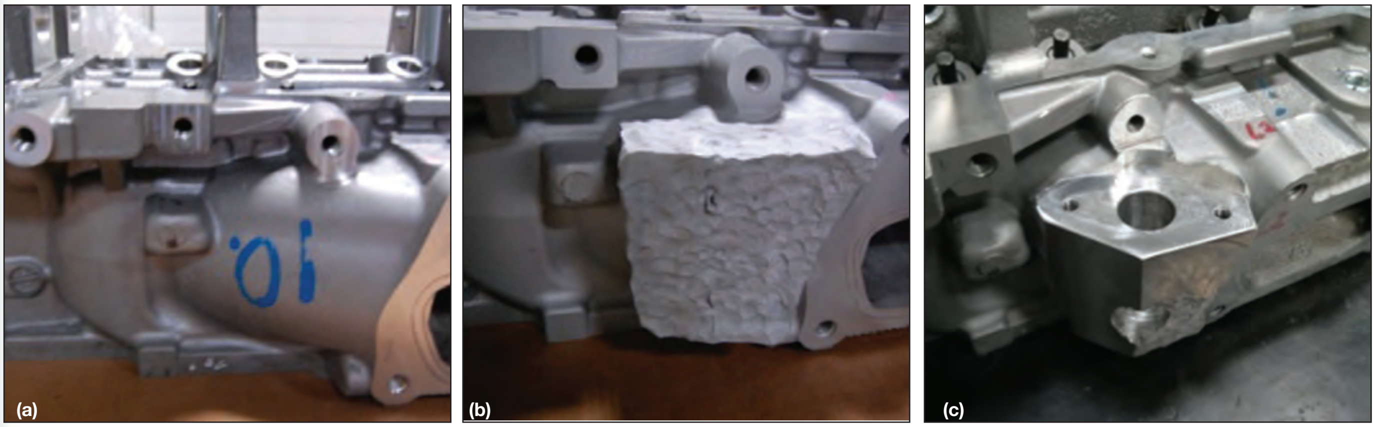

Fig. 3 — *Freeform feature added to a prototype machine component by cold spraying. (a) Prior to spraying, (b) as sprayed, (c) finished.*

ing on such developments and, in the near future, cold spray may become a reliable and practical technology that will enable 3D printing of engineering components at low temperatures. **iTSSe**

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