SHOCKWAVE INDUCED SPRAYING

Artist's rendition of the new SISP technology.

This family of spraying technologies is uniquely suitable for depositing a range of temperature-sensitive and advanced materials.

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Shockwave Induced Spraying (SISP) is a new solid-state spray process for deposition of metals, alloys, cermets, and polymers on virtually any type of substrate at lower temperatures and higher deposition efficiencies and rates than traditional thermal spray processes. Similar to cold gas dynamic spraying (or cold spray), SISP can produce thick coatings on a variety of surfaces at reduced temperature, minimizing thermal effects such as oxidation, tensile residual stresses, and metallurgical transformations. It can enhance surfaces for corrosion protection, thermal insulation, thermal dissipation, wear resistance, electrical conductivity, restoration, and other applications without the detrimental effects of elevated process temperatures.

This article reviews the working principles as well as potential benefits of SISP technology for a number of applications.

Shockwave induced spraying

Shockwave Induced Spraying is a patent-pending process originally developed at the University of Ottawa in 2001. In SISP, fast opening/closing of a control valve downstream of a high-pressure gas source generates trains of shockwaves that compress the gas in front of them as they travel through a straight nozzle. This creates a pulsed (10 to 30 Hz) heated supersonic flow, in which each pulse of compressed gas is matched with a metered batch of powder. As the gas pulse passes through the powder dispensing zone, the powder is picked up, heated (below its melting point), and accelerated down the nozzle, as illustrated in Fig. 1. In contrast to cold spray, a converging-diverging nozzle is not required.

In the SISP process, the achievable gas Mach number of pulsed flows is limited to the low supersonic regime. However, powders in SISP are actually heated during their acceleration due to

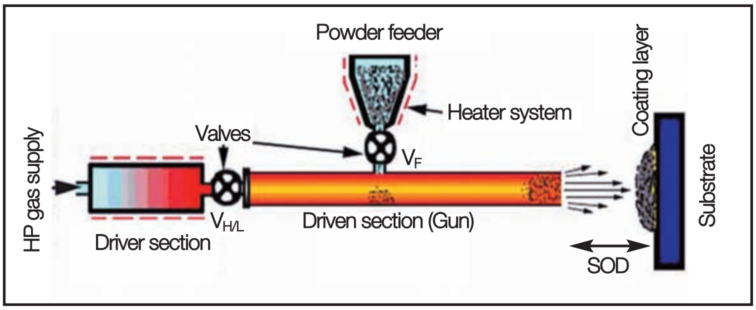

Fig. 1 — Schematic of Shockwave Induced Spraying (SISP). $V_{H/L}$ *is the main gas control valve.* V_F *is the feeding control mechanism, and SOD is the stand-off distance.*

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Table 1 — Comparison of process conditions for solid-state spraying technologies

Process	SISP	CGSP-L	CGSP-H**
Gas pressure, bar	10 – 48	5 - 10	10 - 42
Pressurized powder feeder required	No	No	Yes
Gas temperature, °C	200 – 900	600 max	800 max
Heater power, kW	8 - 10	3.3 – 4.5	17 - 47
Gas velocity, m/s	400 – 900	700 - 900	700 - 1200
*Nitrogen consumption, SCFM; 600°C for SISP; 7 bar / 500°C for CGSP-L ; 35 bar / 600°C for CGSP-H	24	10	45
*Helium consumption (SCFM); 600°C for SISP ; 7 bar / 300°C for CGSP-L; 35 bar / 600°C for CGSP-H	35	31	77
Particle velocity, m/s	250 – 700	300 - 550	600 – 900
*Peak deposition efficiency	85%	45%	90%

*Deposition efficiencies and gas consumption values are for optimized process parameters. **Helium gas consumption for CGSP-H as per Celotto et.al. "The economics of the cold spray process," chapter in *The Cold Spray Materials Deposition Process*, Edited by V.F. Champagne, CRC Press LLC, 2007, pp 72-101.

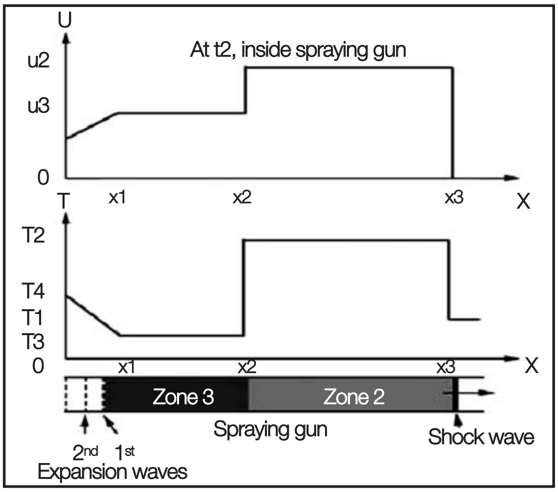

Fig. 2 — Evolution of gas velocity (U) and temperature (T) along the axis of a cylindrical nozzle for the SISP process.

the compression induced by the shockwaves (Fig. 2). This differs from cold spray, in which the gas jet cools down as it expands in the diverging section of the DeLaval nozzle. As a result of particles being heated during flight, the critical particle velocity at which solid-state bonding takes place is effectively lowered. The total combined kinetic and thermal energy of particles results in high deposition efficiencies and rates for an extended selection of materials, including steels, titanium, and cermets.

This more-efficient management of thermal energy at lower particle velocities, along with intermittent gas flow, are key factors in reducing energy and gas consumption. As a result, high levels of performance can be achieved at lower capital and operational costs than possible with CGSP-H. Similar to CGSP-L and CGSP-H, the spray materials never approach their melting point. (See sidebar for discussion of cold spray CGSP-H and CGSP-L technologies.) Table 1 compares the operating requirements of commercially available cold spray systems, while Figures 3 and 4 compare the cost and productivity of several cold and thermal spray processes.

Process details

The range of materials and the metallurgical quality of cold spray deposits largely depend on a combination of particle properties and particle velocities that may be attainable upon impact. Be-

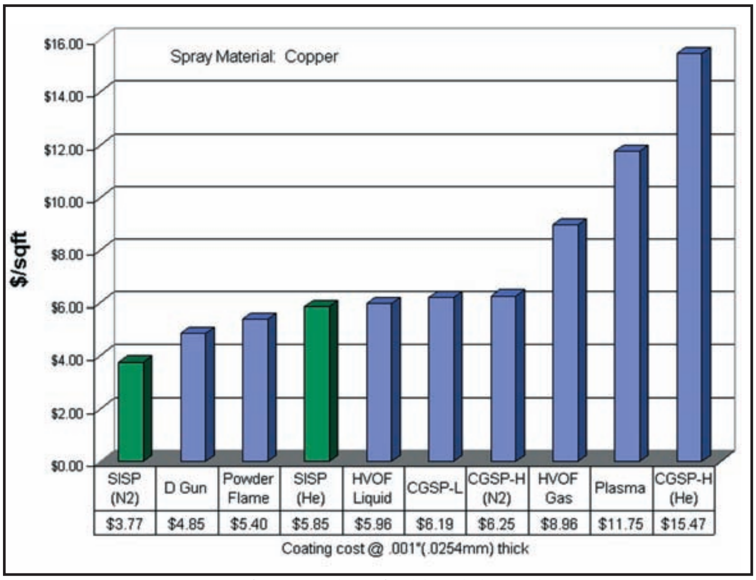

Fig. 3 — Cost comparison for a number of cold and thermal spray processes (includes capital acquisition - amortized over five years, and operational costs excluding labor costs).

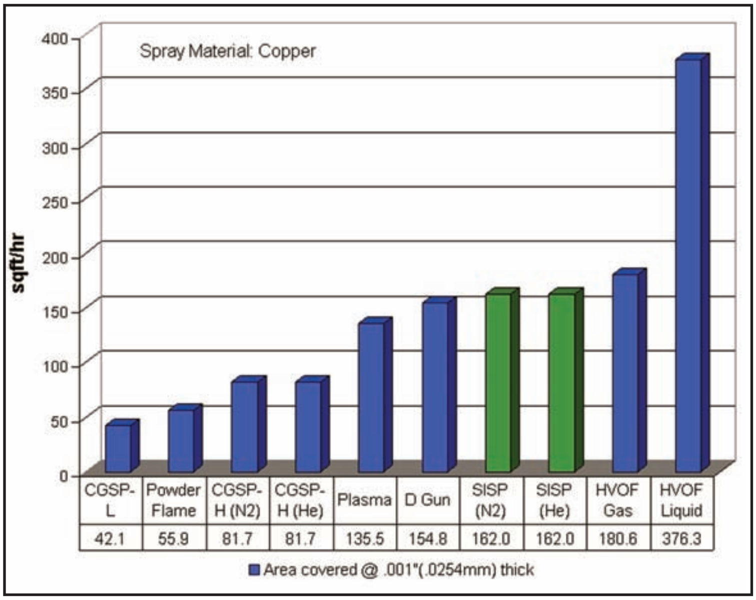

Fig. 4 — Productivity comparison for several cold and thermal spray processes.

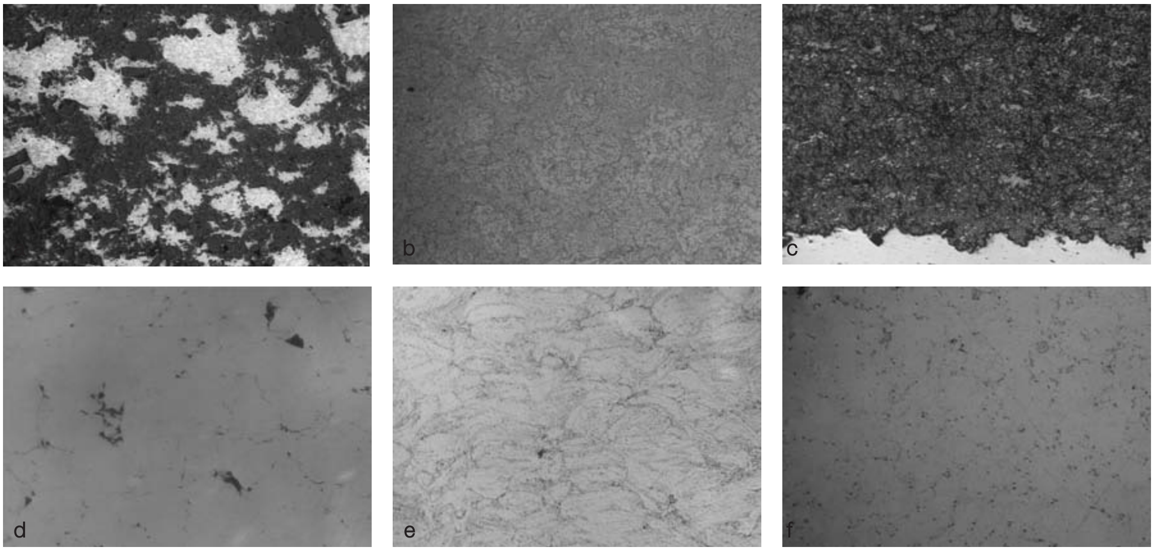

Fig. 5 — Microstructural characteristics of deposits made with SISP technology. a. Aluminum-silicon b. Stainless steel 410 c. WC-Co-Cr d. CoNiCrAlY e. Commercially pure copper f. Titanium

cause of its low density, helium provides the highest gas velocities, which in combination with its noble nature, allows for the widest selection of sprayable materials. However, helium is expensive and in short supply. Therefore, whenever helium is required, specialized recovery/recycling equipment must also be specified to reduce the operating cost.

Nitrogen is affordable and abundant, but the attainable gas velocities are naturally lower than with helium. This limits the range of materials that can be sprayed with nitrogen. Dry air offers the least expensive alternative but the narrowest range of sprayable materials.

The new SISP process provides a unique advantage for helium usage when required. The low density of helium permits pulsing at higher frequencies, which minimizes gas consumption compared to continuous flow systems.

Also similar to cold spray, rapid interfacial plastic deformation on impact is key for particle bonding. Therefore, effective powders for SISP are materials that exhibit some ductility at the impact temperature. Mixtures of metals and ceramics can be successfully sprayed onto metallic surfaces. Conversely, metal powders can be successfully applied to ceramic substrates.

The SISP process is most suitable for OEM production applications in which high productivity and low operating costs are paramount. Examples include thick copper coatings for printing rolls, sputtering targets, anti-corrosion coatings, busbars for photovoltaic and heated glass, EMI/RFI shields, WC-Co for chrome plating replacement, low-friction coatings, thermal barrier coatings, brazing, bio-compatible coatings, nano-structured coatings, and amorphous coatings. Figure 5 illustrates microstructures of a number of deposits produced by SISP.

One of the greatest benefits of solid-state technologies is the ability to spray materials at low temperatures, thereby suppressing any detrimental metallurgical transformations or thermal reactions in both deposit and substrate. By avoiding oxidation, grain growth and recrystallization, phase changes, and thermal stresses, this technology is uniquely suitable for depositing a range of temperature-sensitive and advanced materials.

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Cold gas dynamic spray

Cold spray emerged in the 1980's when researchers at the Institute of Theoretical and Applied Mechanics of the Russian Academy of Sciences in Novosibirsk, demonstrated that when metal powders are accelerated to velocities above a material/temperature-dependent threshold, particles could bond to the substrate upon impact.

This was different from traditional thermal spraying, in which feedstock materials are melted and propelled against the substrate to produce a layered splat deposit. The elevated process temperature often results in undesirable oxidation, porosity, metallurgical transformations, and tensile residual stresses. These drawbacks were the main drivers for development of cold spray technology.

Today, two cold spray technologies are commercially available: high-pressure and low-pressure. In high-pressure cold spray (CGSP-H), helium or nitrogen acts as a propelling gas at high pressures (up to 55 bar). The gas is accelerated to supersonic speeds (600 to 900 m/s) by heating it up to 800°C and forcing it through a converging-diverging (DeLaval) nozzle.

The feedstock powder is introduced into the high-pressure zone of the nozzle, in front of the nozzle throat. The levels of particle kinetic energy attainable are sufficient to spray a wide array of materials with high deposition efficiencies and rates. However, the need for continuous consumption of high-pressure, high-cost carrier gases, as well as the high capital cost of the equipment, make this process economically restrictive for many applications.

Low-pressure cold gas-dynamic spray follows similar physical principles of propelling and consolidating powder materials onto substrates. However, propulsion is achieved by air or nitrogen at reduced pressures (5 to 10 bar) and lower gas temperatures (up to 550°C). The feedstock is introduced downstream into the divergent section of the nozzle at low pressures. Therefore, CGSP-L systems are simpler, smaller, and less expensive to operate, leading to the evolution of portable CGSP-L equipment.

Because of the lower levels of kinetic energy, portable CGSP-L systems are best suited for spraying ductile feedstock materials such as aluminum, tin, and zinc, onto materials such as aluminum, magnesium, steel, and ceramics. Metal powders are often blended with aluminum oxide or other ceramic powders to enhance sprayability.

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