Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 21 (2018) 361–368

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

15th Global Conference on Sustainable Manufacturing

# Structural repair using cold spray technology for enhanced sustainability of high value assets

Christian A. Widener[a,b]*, Ozan C. Ozdemir[a], and Michael Carter[a]

[a]*South Dakota School of Mines and Technology, 501 E. St. Joseph St., Rapid City, SD 57701, USA*
[b]*VRC Metal Systems, LLC, 525 University Loop, Rapid City, SD 57701, USA*

**Abstract**

Cold spray technology has been in significant development since the early 1990s, however, not until recently has it begun to approach near wrought like properties for metals and alloys of aluminum, copper, nickel, titanium, as well as steels, stainless steels, superalloys, and refractory metals like niobium and tantalum. These advancements have come through the use of high pressure cold spray equipment and a greater fundamental understanding of the process variables. As a result, numerous applications have been developed for repairing high cost and long lead time parts for the aerospace and defense market, as well as a broad range of commercial markets such as oil & gas, transportation, and heavy industry. In particular, parts with lead times in excess of 12 months have been successfully repaired and re-introduced into service. This saves not only the direct cost of the part, but also returns the system to service much sooner. Cold spray is an additive manufacturing technology that uses heated high-pressure inert gas to accelerate metal powders through a converging-diverging de Laval nozzle above the critical velocity for deposition onto a substrate. The process produces only mild heating of the substrate compared to most conventional metal deposition or welding technologies, hence the nomenclature of "cold" in cold spray, even though there is heating of the gas in almost all cases. There are also no toxic fumes or other harmful emissions from cold spray because the accelerant gases are: 1) inert (helium, nitrogen, or air), and 2) the heating source is electric and is controlled at temperatures below the melting temperature of the material being sprayed. Furthermore, because parts are being repaired and refurbished rather than replaced, there is tremendous cost, energy, and overall environmental benefit, making cold spray a very "green" technology and an excellent technology for enhancing the long-term sustainability of high value assets.


Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing (GCSM).

* Corresponding author. Tel.: +1-605-394-692; fax: +1-605-394-524.
*E-mail address:* christian.widener@sdsmt.edu

2351-9789 
Peer-review under responsibility of the scientific committee of the 15th Global Conference on Sustainable Manufacturing (GCSM).
10.1016/j.promfg.2018.02.132

*Keywords:* cold spray; repair; refurbishment; metal deposition; thermal spray; chrome replacement

## 1. Introduction

Cold spray technology (CS), also referred to as supersonic particle deposition (SPD) and cold gas dynamic spray (CGDS), is in the family of other thermal spray processes, but is unique because it is a completely solid-state deposition technology. Developed at the Russian Academy of Sciences in the 1980s and patented in the US in 1990 [1], cold spray has been around for a while, but it progressed slowly until the introduction of high pressure cold spray systems around 2007, which began yielding better properties [2-4]. Since 2013, major advancements have been occurring in the technology as additional equipment has become available and the fundamentals of the process are now much better understood [5-7]. Cold spray is an additive manufacturing technology that uses heated high-pressure inert gas to accelerate metal powders through a converging-diverging de Laval nozzle above the critical velocity for deposition onto a substrate. Upon impact particles deform, creating high strains and localized plasticization of the material so that a combination of both mechanical interlocking and metallurgical bonding can be achieved [7,8].

In this paper, current successfully repaired and qualified applications will be discussed, as well as the material properties achievable and their comparison to traditional wrought and cast materials that it is being applied to. Examples of successfully repaired parts include aluminum valve actuator internal bores [9], magnesium castings [10], aircraft skin panels [11], titanium hydraulic lines [11], as chrome replacement for steel shafts [12], gas turbine engine parts [13], aluminum molds [14], high strength steel parts [15], and many more. The paper will also discuss the development process for designing and qualifying a repair, as well as a basic understanding of the equipment and costs involved in implementing the repairs.

**Nomenclature**

| | |
|---|---|
| CS | cold spray |
| SPD | supersonic particle deposition |
| CGDS | cold gas dynamic spray |

### *1.1. Process Description*

Cold spray is a low temperature thermal spray process that uses primarily kinetic energy rather than thermal energy to form a coating or near net shape deposition on a wide range of substrates. The process can deposit metallic particles or combinations of metallic and non-metallic particles and consolidate them by means of ballistic impingement upon a suitable substrate. The particles utilized can be from commercially available powder sources and typically range in size from 5 to 50 μm. The powders are then accelerated to from 300 to 1,400 m/s when injected into a high pressure, pre-heated gas stream and accelerated through a converging-diverging De Laval nozzle, as shown in Fig. 1. The pressurized gas is expanded to supersonic velocities, approximately Mach 1-3 [16,17]. The particles, initially carried by a separate gas stream, are injected into the nozzle either prior to the throat of the nozzle or downstream of the throat. The particles are subsequently accelerated by the main nozzle gas flow and impacted onto a substrate after exiting the nozzle.

Upon impact, the solid particles deform and create a bond with the substrate [17,18]. The bonds are comprised of both mechanical interlocking, as well as metallurgical bonding by dynamic recrystallization at high shear strain boundaries. As the process continues, particles continue to impact the substrate and form bonds with the consolidated material resulting in a uniform deposit with very little porosity and high bond strength. The term ‘cold