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Economic impact of Cold Spray in North American aerospace industry: A case study

1 Background

Cold Spray is a solid-state coating process that uses a high-speed gas jet to accelerate powder particles towards a substrate where metal particles plastically deform and consolidate upon impact. The term “Cold Spray” refers to the relatively low temperature involved in the process which is typically much lower than the melting point of both the spray and substrate materials. Although the concept of “cold spraying” metallic materials onto substrates goes back to the early 1900’s, it was not until the 1980’s that the applicability of this technology was demonstrated and commercialised by the Institute of Theoretical and Applied Mechanics of the Academy of Sciences in Novosibirisk [1] (high pressure cold spray) and then by the Obninsk Center for Powder Spraying (OCPS) [2] (low pressure cold spray) in the former Soviet Union.

In cold spray equipment, air, nitrogen or helium at prescribed pressures and temperatures are injected into converging-diverging (DeLaval) nozzles to obtain a supersonic gas jet. The spray material, in powder form, is introduced upstream the nozzle throat (high pressure cold spray), or downstream into the diverging section of the nozzle (low pressure cold spray) (Fig. 1) to accelerate and collide against the substrate. Collisions create rapid material deformation that promotes a mixture of mechanical and metallurgical bonds. Each type of spray material requires a minimum level of kinetic energy above which acceptable bonding to the substrate may occur. The type of gas, gas pressure, gas temperature, and nozzle design determine the amount of kinetic energy available to accelerate particulate. The characteristics of the spray powders, such as particle size, shape, chemistry, and diversity as well as the degree of surface preparation, influence the easiness to attain desired bond strengths. Many common engineering materials, particularly blends of materials, can be successfully cold sprayed at relatively low pressures (less than 40 bars), low gas temperatures (below 600°C), and using nitrogen or air.

Since adhesion of the metal powder to the substrate and deposited material is achieved in the solid state, the characteristics of cold spray deposits are quite unique, making cold spray suitable for consolidating well bonded, low porosity, oxide-free materials and/or combination of materials on a wide range of substrate materials. These attributes include the ability to deposit a wide range of materials on temperature-sensitive substrates, such as for the case of repair and restoration of high value components for aerospace.

Fig. 1 • Commercial down-stream injection cold spray system (Source: CenterLine Windsor Ltd.).

Fig. 2 • Integrated drive generator of Boeing 747 (Source: L.J. Walch).

2 Cold Spray in aerospace

For many years, aluminium and magnesium alloys have been the materials of choice for aircraft structural and non-structural components, such as cast metal housings. Well known performance characteristics, established fabrication methods and recent technological advances are just a few of the reasons for the continued confidence in these alloys. The life span of an aircraft often surpasses the commercial availability of spare parts; thus, one challenge for the industry is obsolescence management, which increases the cost of aircraft maintenance. Subsequently, the ability to economically and reliably restore scrapped components becomes an important necessity in aircraft maintenance. Thermal spray processes, such as plasma or arc wire spray, have traditionally been used with limited success due to their inherent excessive heat, porosity, distortion, oxide inclusions, and masking requirements.

2.1 Case study: Repair of IDG housings

Over the last decade, an increasing number of aerospace certified thermal spray shops in North America have adopted and/or developed numerous cold spray repair specifications to bring back to original OEM specifications hundreds of high value aircraft components both for commercial and military aviation. The ability of cold spray technology to create well-bonded, low porosity, oxide-free metal repair at low temperatures became quite attractive for restoring tight tolerance aircraft castings made of magnesium and aluminium which do not tolerate distortion.

Today, magnesium or aluminium cast housings for integrated drive generators (IDG) (Fig. 2) represent one good example of a particular high value aerospace component that is regularly repaired by cold spray. These are considered non-critical components, yet quite expensive to replace, not to mention the long haul turnaround. An IDG is an in-flight power generation device that converts the variable rotational speed of an aircraft engine into constant speed to drive a built-in AC generator. Typically pitting corrosion, wear, and tear of the housing produce dimensional issues that affect performance beyond normal repair. Many of the failures are located at tight tolerance heat-sensitive areas such as stator bores, exciter bores, pilots, mounting pads and mating faces (Fig. 3). These areas are challenging to be dimensionally restored using traditional thermal spray. Consequently, cold spray has become an economically viable alternative. Cold spray repaired devices are currently accumulating flight hours in many commercial aircraft including Boeing 737NG, 747, 777; Airbus A320, A330, and A340.

2.2 Cold Spray qualification procedure

The qualification procedure followed by most FAA certified (FAA Federal Aviation Administration) spray shops include, first, the selection of an appropriate cold spray grade powder material; then, the development and optimisation of cold spray process parameters to produce coatings within the required specifications. Property validation is often conducted following ASTM C633 bond strength testing, metallographic examinations (Fig. 4) and 90° bend testing per the OEM's repair validation specifications (e.g. Hamilton Sundstrand SPR52). For this particular case,

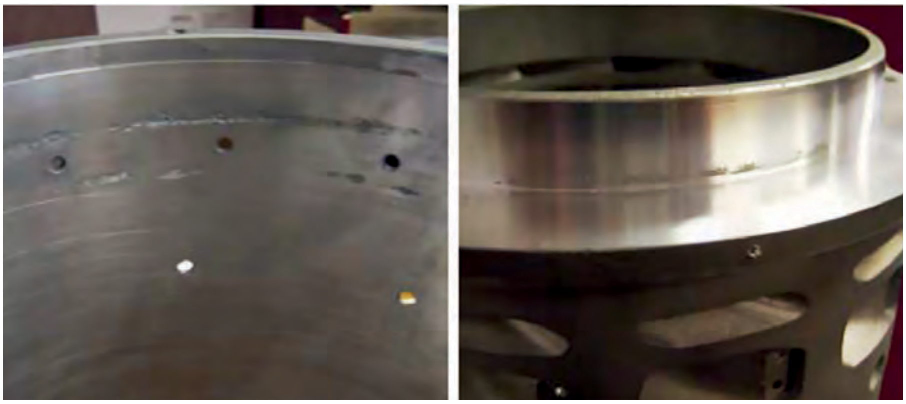

Fig. 3 • Pitting corrosion damage in an APU generator housing of Boeing 747 (Source: L.J. Walch).

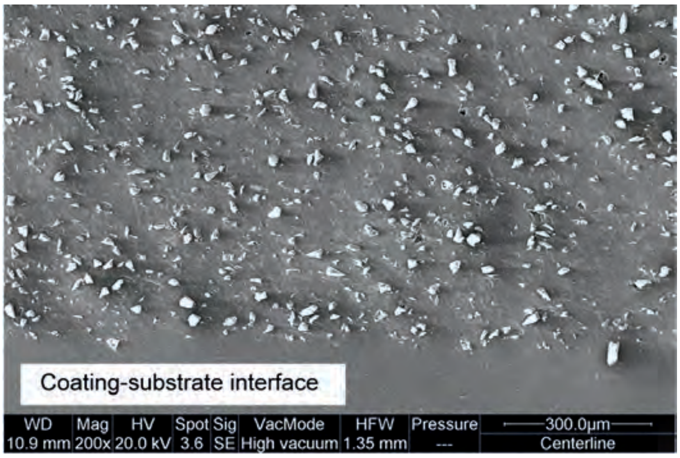

Fig. 4 • Microstructure of a typical cold spray grade aluminium-alumina composite (SST A0050) used in the repair of aluminium and/or magnesium castings. The substrate is aluminium 6061 (Source: CenterLine Windsor Ltd).

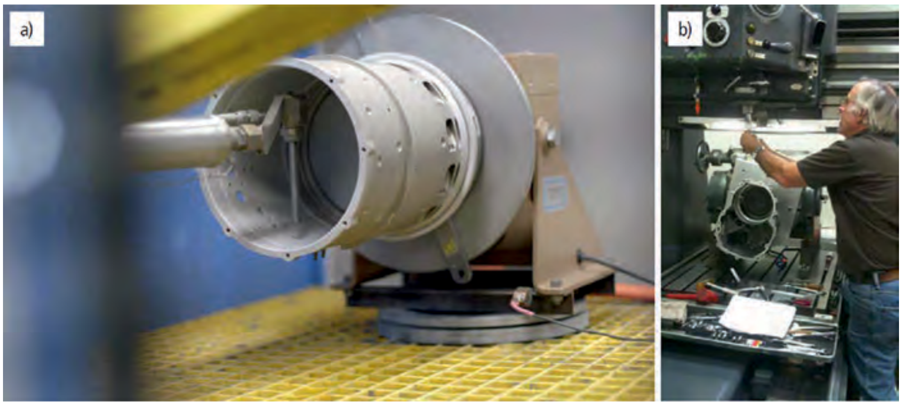

Fig. 5 • Robotic cold spraying (a) and post-machining operation with the cold spray process (b).

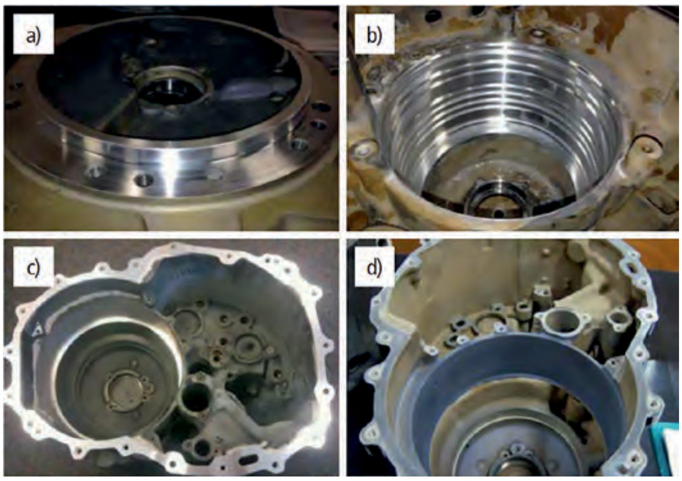

Fig. 6 • Repaired and finished components: a) pilot OD, b) stator bore ID, c) housing mating surface, and d) housing bore (Source: L.J. Walch).

specifications call for a minimum of 3,000 psi (20 MPa) adhesive/cohesive strength, less than 2% porosity, no cracks, no lack of bonding, and 90º tensile bends around a 6 mm radius, without any chipping or spalling.

2.3 IDGs repair procedure and quality assurance

General guidelines for the commercial repair of IDGs include:

a) Removal of existing corroded and/or damaged surfaces
b) Pre-machining as necessary to facilitate cold spray deposition
c) Surface preparation including grit-blasting or other methods for increasing surface roughness
d) Cold spraying using manual or robotic guns (Fig. 5a)
e) Post machining of the repair per OEM engineering specifications (Fig. 5b)
f) Visual inspection
g) Dimensional inspection
h) Non-destructive examination
i) Finishing where required (painting and/or anodising) to improve corrosion protection (Fig. 6).

2.4 Cold Spray economic viability

The main justification for the use of cold spray in the restoration of these types of components is the ability to recover them at a fraction of their OEM replacement cost – this is assuming that the part is commercially available. In many instances the component is simply no longer available. Fig. 7 compares the average cost of replacement against the cost of cold spray restoration for a number of IDGs.

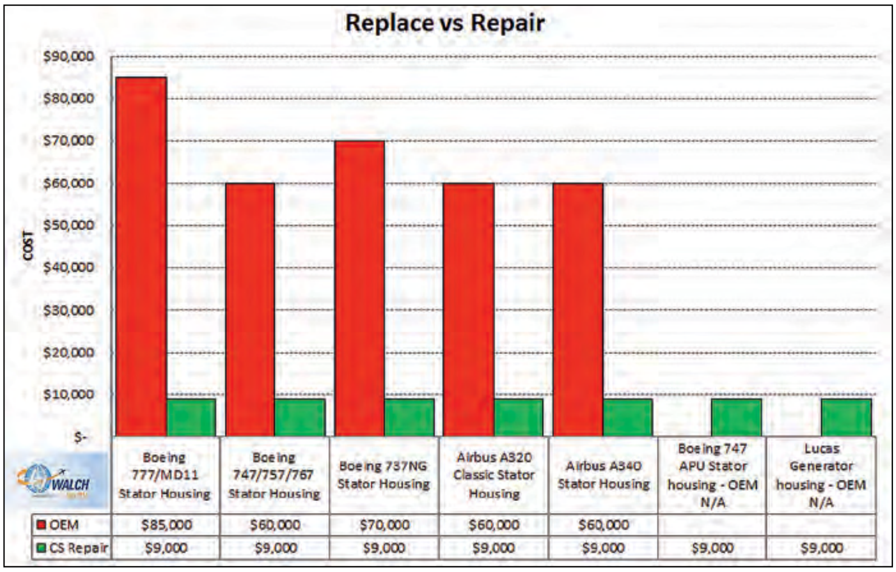

Fig. 7 • Cost of cold spray repair versus replacement for various IDGs (Source: L.J Walch).

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