COLD SPRAY ADDITIVE MANUFACTURING

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Abstract

High Pressure Cold spray (CS) belongs to the family of thermal spraying technologies. The technology consists in accelerating microscopic particles to supersonic speed and depositing them on a substrate, where kinetic energy is converted into deformation and thermal energy at the moment of impact. Compared to conventional processes, CS offers particular advantages, as the spray material is neither melted on nor melted off during the process. This fact minimizes the thermal influence on the layer and substrate. A typical CS beam is narrow and well-defined. Because CS can be used for the fabrication of near-net-shape articles this technology has been recently applied as an additive manufacturing process. With cold spray is possible to produce individual components. It is also possible to repair damaged components. In comparison with fusion based high temperature additive manufacturing processes, CSAM (cold spray additive manufacturing) has shown to retain the original properties of the feedstock, to produce oxide-free deposits, and to not influence underlying substrate materials during manufacturing process. This article aims to provide a brief introduction to cold spray technology and CSAM. The technology and process are demonstrated on a test-manufactured copper sample.

Keywords: High pressure cold spray, additive manufacturing, CSAM, cooper

1. INTRODUCTION

High pressure cold spray (HPCS) is a novel additive manufacturing (AM) technique that belongs to the category of cold spray processes. Cold spray processes use a high-speed gas jet to accelerate solid particles and impact them onto a substrate, forming a coating or a part. Unlike other thermal spray processes, cold spray does not involve melting or softening of the particles, thus avoiding oxidation, decomposition, or phase transformation of the materials. HPCS is a special type of cold spray that uses very high gas pressures (up to 60 MPa) and temperatures (below 1200 °C) to achieve supersonic velocities (up to 1200 m/s) of the particles. The high kinetic energy of the particles enables them to plastically deform and bond with the substrate and each other upon impact, forming a dense and defect-free layer [1].

HPCS can produce coatings or near-net-shape parts with thicknesses ranging from micrometres to centimetres. The quality and properties of the HPCS products depend on various factors, such as the material characteristics, the gas parameters, the nozzle geometry, the powder feed rate, the substrate condition, and the scanning speed. HPCS can achieve high deposition rates (up to 50 kg/h) and high deposition efficiencies (up to 90 %) compared to other AM methods. HPCS can also produce parts with minimal thermal effects, such as low oxidation, low porosity, low residual stress, and low distortion. These features make HPCS suitable for repairing or enhancing components that are sensitive to heat or require high mechanical performance [2].

HPCS has been applied to various materials, such as titanium, aluminium, copper, nickel, and their alloys. These materials have high ductility and low melting points, which are favourable for cold spray bonding. HPCS can also create composite or functionally graded materials by mixing different powders or changing the powder composition during spraying. HPCS can be used to fabricate parts with complex geometries or fine features by using masks or robotic manipulators. HPCS can also be combined with other AM methods, such as laser cladding or selective laser melting, to create hybrid structures with enhanced properties [2,3].

However, HPCS also has some challenges that limit its widespread application. One of the main challenges is the limited material selection. Only ductile and low-melting-point materials can be sprayed by HPCS, while brittle or high-melting-point materials are difficult or impossible to bond by cold spray. Moreover, some materials may require preheating or post-treatment to improve their adhesion or cohesion. Another challenge is the high gas consumption and cost of HPCS. The high gas pressure and flow rate require large and expensive gas compressors and tanks. The gas consumption also affects the environmental impact and safety of HPCS. A third challenge is the complex process parameters and optimization of HPCS. The optimal parameters for HPCS depend on the specific material system and application, and may vary significantly for different cases. Therefore, extensive experimental trials and numerical simulations are needed to determine the best conditions for HPCS.

The possibility of using Cu powder for additive manufacturing using cold spray was tested. As part of the experiment, a sample was produced and subsequently analysed [3].

2. MATERIALS AND METHODS

2.1 Material and equipment

Commercially available Cu powder provided by SENTESBiR was used for the additive manufacturing of the component. The parameters of the deposited powder are given in **Table 1**. The grain size analysis was carried out.

Table 1 Parameters of deposited powder

Cu [wt.%]	**>99%**
Grain size	20.26 ± 10.81 µm

Impact Gun 6/11 EvoCSII was used as the deposition device. A convergent divergent nozzle Injector OUT1 with a length of 160 mm, made of SiC material, was used.

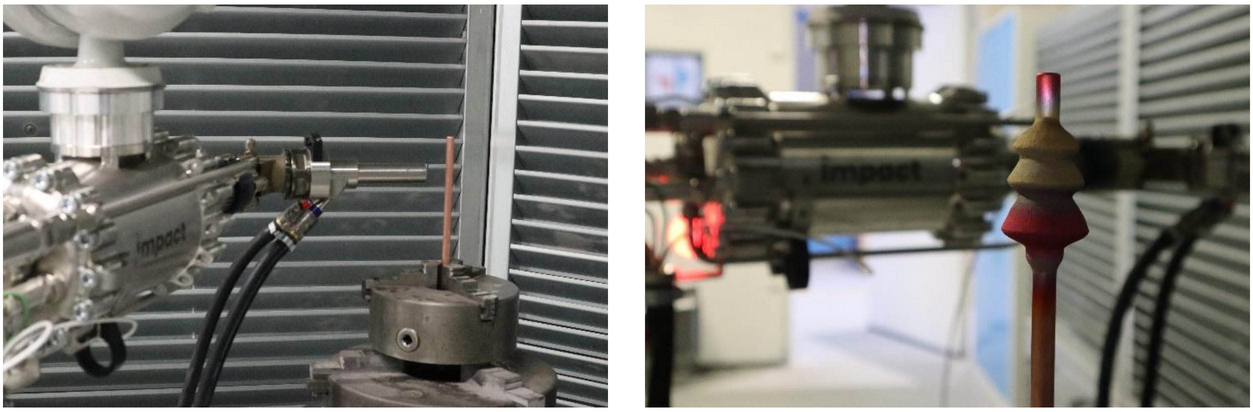

Figure 1 Impact Gun 6/11 EvoCSII

2.2 Deposition process

First, 1 layer of Cu11000 powder was deposited on a 10 mm diameter copper bar along the entire length of the part. Subsequently, individual "floors" were formed in three sections, see **Figure 2**. The deposition in the individual layers was compensated by the departure of the robot by a distance of 1.7 mm with each subsequent layer. For the 10th pass, the layer was 12.8 mm, i.e. there was a 9x compensation 9*1.7 = 15.3 mm, the total distance was therefore 45.3 mm, which at a layer thickness of 12.8 mm makes the deposition 32.5 mm. The deposition was therefore kept around 30 mm all the time. What was not compensated for was the change in rotational speed of the positioner. Thus, the deposition speed for the first and last layer differed slightly (for the larger diameter the rotation speed of the positioner should be less than for the smaller diameter to keep the same circumferential speed). See **Figure 2, Table 2.**

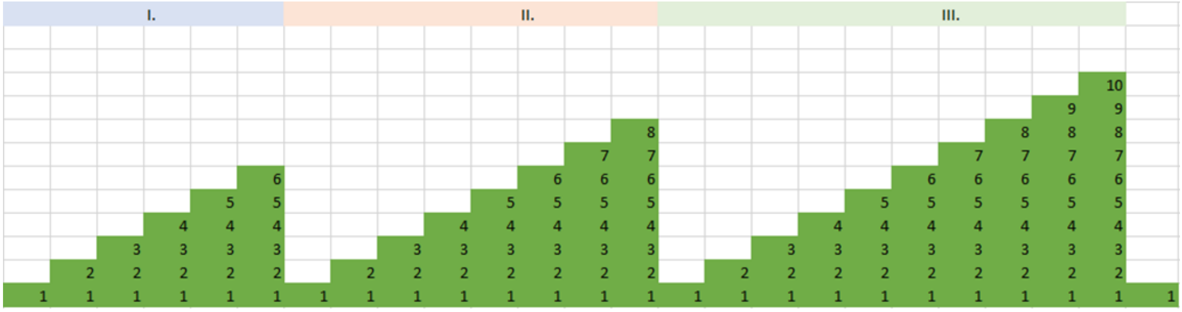

Figure 2 Setting up the robot during deposition

Table 2 Process parameters

Process gas	**N$_2$**
Process gas temperature [°C]	500
Process gas pressure [bar]	30
Number of passes, section 1 / thickness [mm]	6 / 8.26
Number of passes, section 2 / thickness [mm]	8 / 10.57
Number of passes, section 3 / thickness [mm]	10 / 12.8

3. RESULTS

The formed part was machined to the final shape using lathe, sandpaper and then cut on a wire cutter **Figure 3**

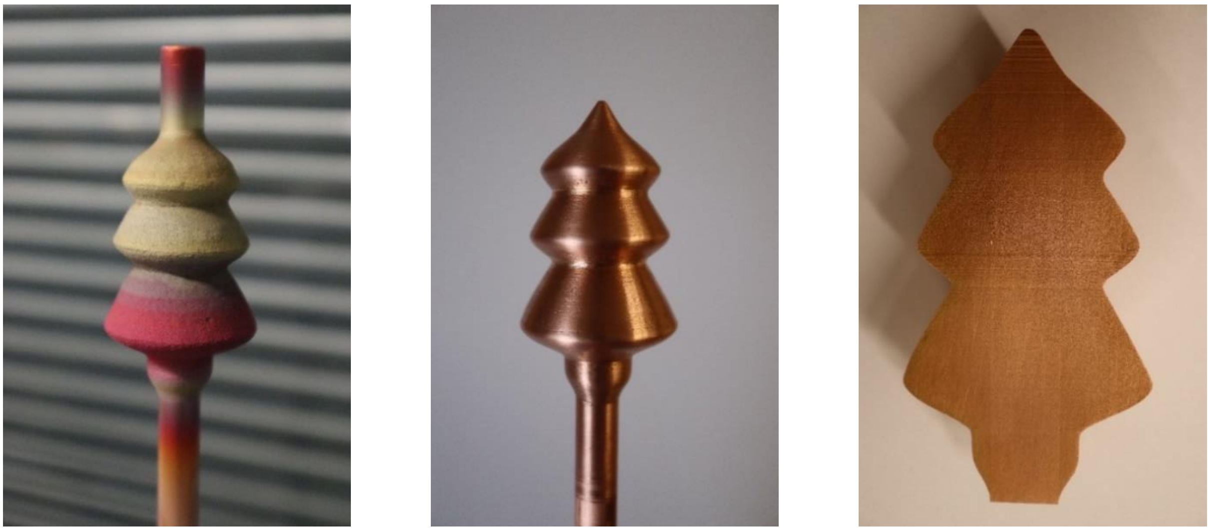

Figure 3 Part after deposition (left), after grinding (middle), after cutting (right)

Metallography was performed using SiC 320, 500, 800, 1200, 4000 abrasive papers and subsequently polished on MD Galaxy Beta (9 μm), MD Dac (3 μm) and MD Nap (1 μm) polishing screens. **Figure 4**

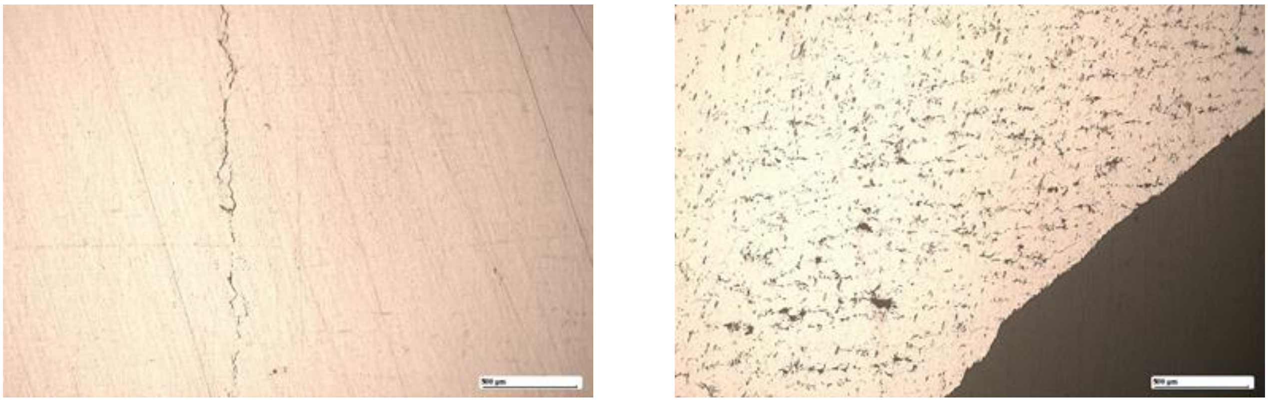

Figure 4 Material structure - different deposition areas

As the metallography of the material varied depending on the location of the cut, a diagram was created to show the state of the material depending on the part of the sample. **Figure 5**

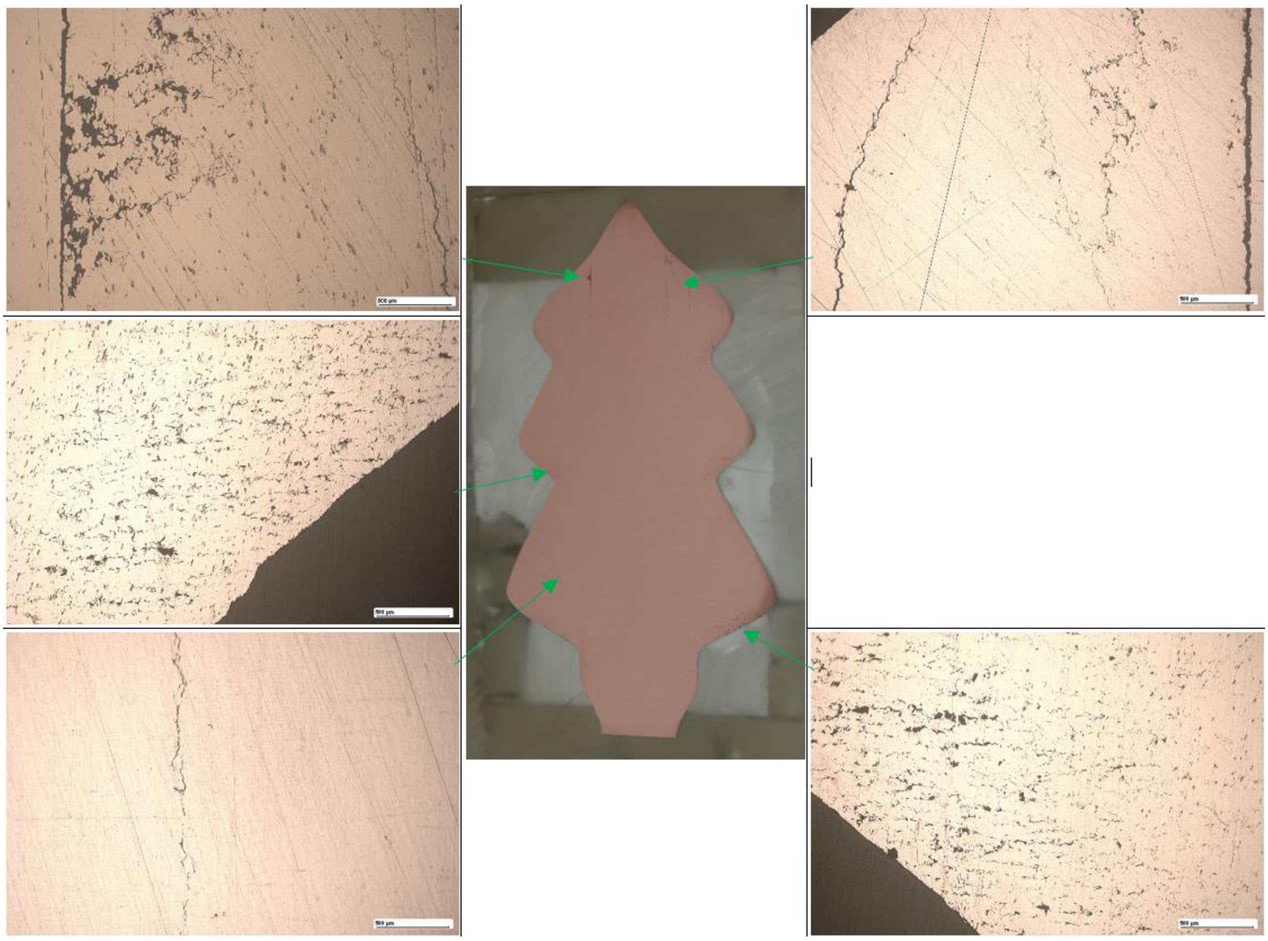

Figure 5 Diagram showing the state of the material depending on the part of the sample

The **Figure 5** shows that there are structures in different regions of the deposited layer that differ. In particular, the different porosity of the Cu material can be seen. The heterogeneity of the structure may be due to the angle of the nozzle [4], which was set at 90° to the substrate. During deposition, the material was deposited and then the angle of deposition was not 90°. Better porosity can be achieved by using He instead of N_2 as a carrier gas. Helium has higher sonic velocity due to its low molecular weight (the limiting velocity through the nozzle throat), resulting in higher overall gas velocities, particle speed, and general deposition efficiency and layer quality [5]. The main drawback of using helium as a process gas is its high price, exceeding several times the price of N_2.

Besides increased porosity, the cracks was observed especially in the area of the interface between the substrate and the deposited layer. One of the possible cause of the crack is that they are initiated earlier in the coating due to stress concentration from the shoot peening effect introduced by the cold spray process.[5] Other possible causes of crack could depends on factors as such as the cold spray process parameters, substrate conditions, coating/substrate interactions at the interface and feedstock material properties.[6]

4. CONCLUSION

To demonstrate the suitability of cold spray for additive manufacturing, an experiment was conducted using Cu powder as the material. The results showed that Cu powder could be successfully deposited by cold spray and create a 3d printed structure. The process of fabricating the material involved several challenges and limitations. One of the main issues was quality of the material structure and the bonding between the layer and the substrate. The structure of the deposited material varies depending on the location where the analysis was carried out. The probable cause is the different nozzle angle and peripheral velocity. Both parameters were fixed and did not reflect the change in deposition angle and velocity as the sample diameter increased during deposition. Another parameters of fabrication process, such as temperature, pressure and robot feed can affect the process of deposition. To overcome this problem, it is necessary to work on further optimization of these parameters.

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