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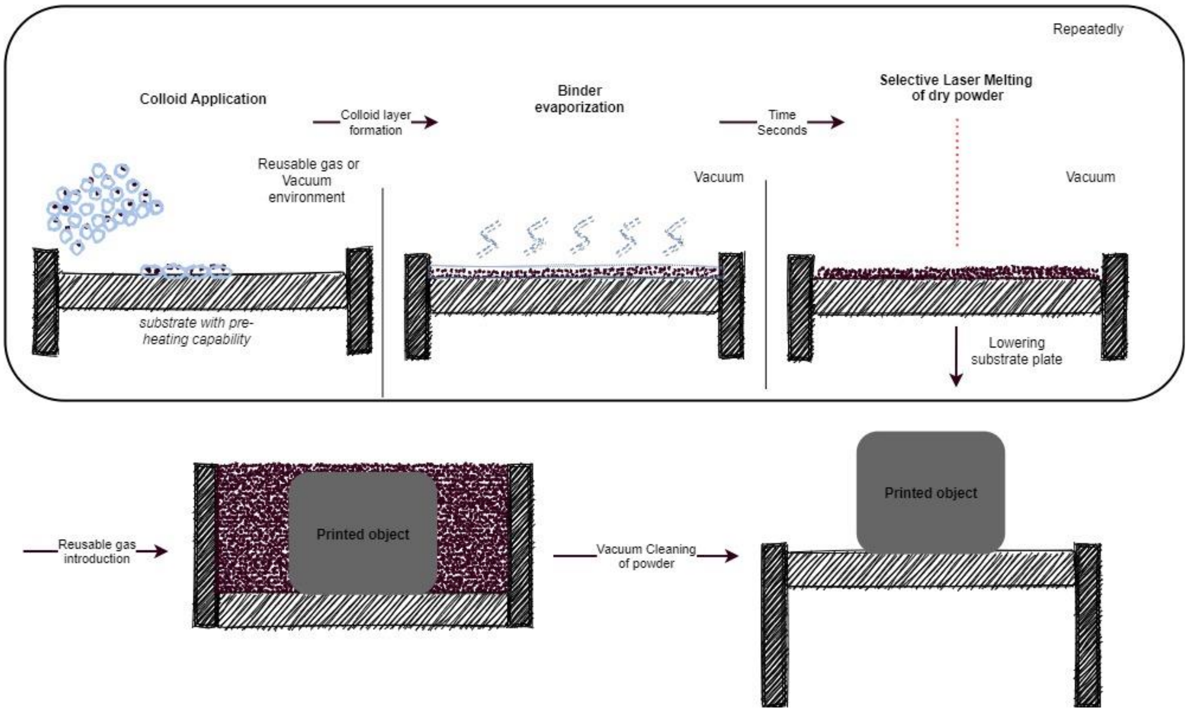

Development of metal Selective Laser Melting (3D printing) technology for microgravity environment with colloid-like feedstock

Executive Summary

Open Discovery Ideas Channel (OSIP)

Activity type: Early Technology Development

Affiliations: Progresja S.A. (Prime)

Activity summary:

In the course of this project, we have developed an additive manufacturing technique firmly rooted in the Powder Bed Fusion methodology, specifically designed to address the challenge of Off-Earth Manufacturing. The unique aspect of the technology lies in the utilization of a specialized feedstock material in form of a colloidal mixture. This material has the remarkable capability to create a rigid and stable powder bed, making it exceptionally well-suited for operation in zero-gravity conditions. While this novel technique certainly comes with its own set of challenges, the project's outcomes demonstrate its capacity to successfully fuse titanium alloy powder in layer-by-layer manner. Furthermore, the specific feeding mechanism designed for this unique feedstock enables consistent and stable powder deposition, showcasing its feasibility for practical applications in zero-G conditions.

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Executive Summary:

At present, the longest period that a crewed mission has gone without a resupply from Earth is held by MIR (119 days from 1998 to 1999) and the longest period that a crewed mission has gone without a resupply beyond LEO is held by Apollo 17 with 12 days from 7th to 19th of December 1972. No crewed spacecraft has travelled beyond LEO since that time. When it comes to mission duration, the ISS is the absolute record holder with 21 years of service since 2nd of November 2000, but it must be noticed that the average ISS mission endurance (time without resupply) is 36 days while the longest period that ISS has not been supplied from Earth is 116 days (data for February 2019). When we consider the fact that for example, a mission to Mars will take between 1000 to 1200 days, the required mission endurance will be two orders of magnitude greater than the longest crewed mission beyond LEO so far. Also given the lack of timely options to abort or resupply, we face the great challenge of supporting future crewed missions beyond LEO. The logistics analyses performed so far indicate that Off-Earth Manufacturing (also: In Space Manufacturing (ISM), On Demand Manufacturing (ODM)) will be a key enabler for crewed missions beyond LEO. And when considering the Off-Earth Manufacturing, one technology is mentioned particularly often, which is Additive Manufacturing.

In recent years, on-Earth metal additive manufacturing has become an established manufacturing technology for aerospace applications. It not only allows for obtaining a better buy-to-fly ratio but also maximizes the design potential for performance improvement and parts' weight reduction. Both Powder Bed Fusion (PBF) and Direct Energy Deposition (DED) processes are currently widely used for prototyping and low-volume production of metal parts. However, the application of those processes is limited when it comes to microgravity conditions.

The PBF process is based on the melting of successive layers of powder, evenly distributed on a powder bed. This powder bed is relatively easy to control in gravity conditions, however, in a microgravity environment, it would immediately turn into a cloud of floating powder which is not only impossible to selectively melt but also potentially explosive. Also, the transportation mechanism of powder particles in microgravity and vacuum conditions is challenging. The powder assisted DED process faces similar problems. Therefore, wire-assisted DED processes have gained the most interest so far when it comes to off-Earth metal additive manufacturing. Studies have shown that the wire-assisted process is relatively easy to control, as the wire feeding mechanism used in on-Earth manufacturing can be almost directly applied for in-orbit conditions offering a satisfactory overall quality of printouts on sample level. However, the wire-assisted DED process can only be described as near-net-shape manufacturing, which implies the necessity of further machining or considerable postprocessing before obtaining a functional part. What is more, the wire feeding faces a lot of issues related to wire tip positioning and its stability during the process. Moreover, feedstock in form of wire needs to be transported in form of spools which take a lot of volume in comparison to powder containers. Compared to DED, the PBF process offers superior part resolution and can produce almost ready-to-use parts which require minimal postprocessing operations. The great advantage is also its versatility and ability to produce very complex geometries with enhanced functionality (such as internal cooling channels).

Therefore, PBF could be more beneficial in terms of expected printouts usefulness and actions should be taken to develop a suitable enhancement for the PBF process that will enable its application in on-orbit conditions. Such actions have been undertaken in realized project.

The innovation behind developed technology lies in its utilization of a novel feedstock type and a corresponding feeding mechanism, enabling the application of Laser Powder Bed Fusion (L-PBF) in vacuum and microgravity environment. This unique feedstock can be effectively used in both microgravity and vacuum conditions, offering advantages in terms of handling, maintenance, and transport when compared to currently available additive manufacturing feedstock types, such as wire

and powder. As a crucial proof of concept, an experiment was conducted using the newly developed feedstock type. The experiment revolved around measuring the mass of the powder deposited onto a substrate plate, on which powder bed was formed, in form of a colloidal mixture. The substrate plate (with the powder bed) was rotated by 180° in relation to the gravity vector. The results revealed that while the amount of powder adhered to the substrate plate varied with the chemical composition of the colloidal mixture, remarkable outcomes were achieved. Specifically, post-rotation, powder losses of only 25%, 16%, and even 0% were observed presenting the adhesion magnitude of powder to substrate plate. This significant finding alone underscores the immense potential of this feedstock type in applications related to off-earth manufacturing, where zero-G conditions will be less demanding by means of powder adhesion forces.

Of great significance is the successful development of a feeder designed specifically for this innovative feedstock type. The feeder system has been rigorously engineered to excel with colloidal mixtures, effectively enabling feedstock atomization in vacuum conditions and the precise formation of a powder bed. This achievement marks a pivotal advancement in feedstock technology. What sets this developed feeding system apart is its reliance on techniques that negate the necessity for additional resources, notably gases. This innovation has undergone rigorous testing to ensure its reliability throughout the entire additive manufacturing (AM) process. Most impressively, it exhibits the capability to function independently of the gravitational vector, underscoring its adaptability and versatility.

To highlight the groundbreaking potential of the innovative AM (Additive Manufacturing) technology, an advanced breadboard was meticulously developed and thoroughly tested in a controlled laboratory setting. This breadboard was specifically designed to utilize a feedstock developed during activity and its accompanying feeder system. The primary goal was to construct a robust platform for fine-tuning laser processing parameters, a critical step that marked a significant achievement.

Through adjustments and refinements, laser processing parameters were optimized, bringing us to the point where technology demonstration was within reach. It was at this point that the ability of this technology to additively produce complex metal elements began to emerge. To demonstrate this potential, the demonstrator took the form of a 10x10x3.5 cubic structure. The development of this demonstrator was a noteworthy endeavour despite significant limitations. Due to time constraints, the height of the demonstrator was limited, which limited the amount of processing optimization that could be performed. Nevertheless, even with these time constraints, the demonstrator was produced additively, layer by layer, using 140 layers with an approximate thickness of 25 µm. This significant achievement convincingly demonstrated the technology's ability to fuse successive layers of metal powder.

Although the quality of the 20x20x3.5 mm sample produced may not yet meet the established standards of commonly used Powder Bed Fusion (PBF) processes, our system's breadboard has convincingly demonstrated the capacity to construct a stable powder bed and fuse metallic powder layer by layer. It's important to highlight that this technology significantly reduces the reliance on gases by utilizing a vacuum, thereby increasing its suitability for extraterrestrial manufacturing applications.

These results highlight the technology's potential, suggesting that with further refinement and advancement of the additive manufacturing process, it has the potential to deliver fully dense printouts. This quality improvement makes it a compelling candidate for integration into the European Space Agency's (ESA) crewed missions, signalling a significant step forward in the search for off-earth manufacturing solutions.

Project achievements:

The achievements of the activity are:

1. Development a colloidal mixture as a novel Additive Manufacturing feedstock type.
2. Development a colloidal mixture applicator (feeding device) capable of operating under vacuum and regardless the gravity.
3. Investigation of the behaviour of colloidal mixture under vacuum and stability of powder bed in relation to a gravity vector (up to minus 1 g conditions).
4. Demonstration and verification of the proposed AM system capabilities in vacuum environment.
5. Evaluation of the novel additive manufacturing process on 20x20x3.5 mm titanium grade 5 sample level.
6. Confirmation of powder bed stability by the rotation of powder bed opposite to the gravity vector with pre- and post-rotation mass measurements of deposited powder.

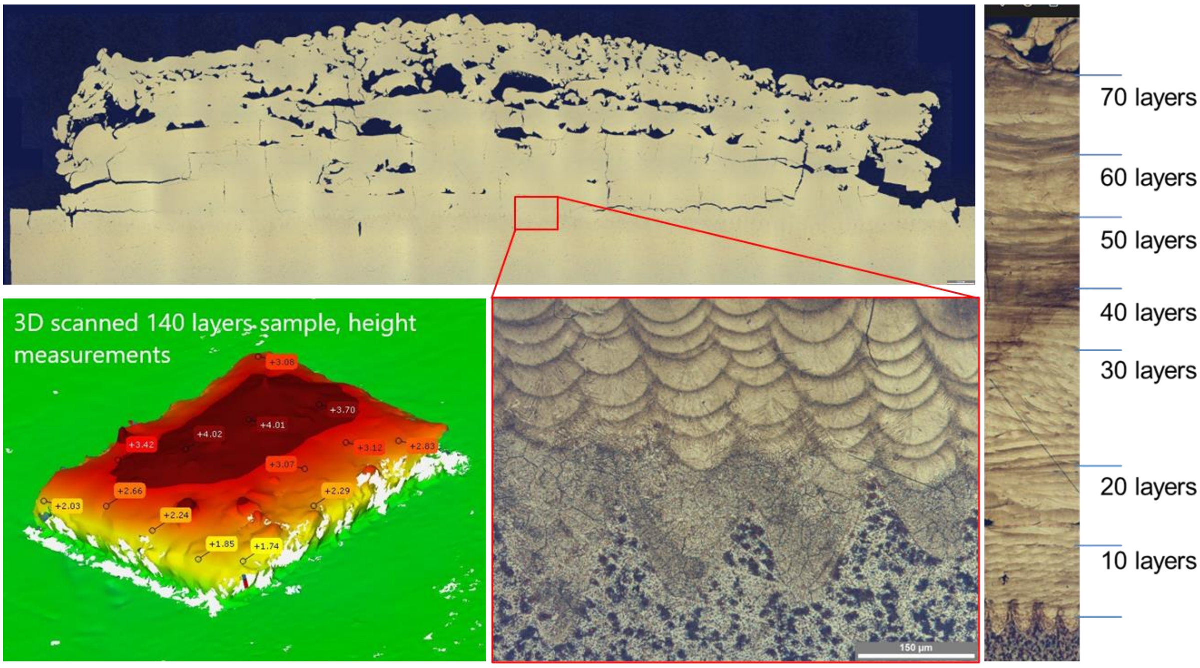

Figure 1 Sample produced with constructed breadboard of developed PBF process in form of 20x20x3.5mm (140 layers) metallic cube