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Metal Additive Manufacturing: A road to Future

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***Abstract*- Metal Additive Manufacturing, also known as metal 3D printing, offers unrivalled design freedom with the ability to manufacture parts from a wide range of materials. Components that would not have even been possible just a few years ago can now be made to high standards using a wide range of metal powders. No longer solely a prototyping technology, Additive Manufacturing is now being used for the production of series components for the most demanding applications.**

***Keywords*- Additive manufacturing, 3D printing, Metal powder, Aerospace.**

I. INTRODUCTION

Additive Manufacturing, also referred to as 3D Printing, is a technology that produces three-dimensional parts layer by layer from a material, be it polymer or metal based. The method relies on a digital data file being transmitted to a machine that then builds the component. metal powder bed fusion is an additive manufacturing technology that uses a high-powered ytterbium fibre laser to fuse fine metallic powders together creating functional 3-dimensional parts. The process is digitally driven, direct from sliced 3D CAD data. For each slice of CAD data, a thin even layer of fine metal powder is deposited across the build plate, then the selected areas of the powder are precisely melted by the laser. This process is repeated building up, layer by layer, until the build is complete. The early adopters of additive manufacturing included high-end automotive, aerospace and consumer goods customers. Applications are growing across industries with increasing use in dental, medical and tooling. Renishaw have dedicated teams providing healthcare solutions.

II. METAL POWDERS

SLM and DMLS can produce parts from a large range of metals and metal alloys including:
- Aluminium
- Stainless steel
- Titanium
- Cobalt chrome
- Nickel

These materials cover the needs of most industrial applications, from aerospace to medical. High-quality metal powder is very important for successful powder bed fusion. In such processes, build material flow rates are optimized through the use of closely packed, spherical metal particles of similar size. Consistent metal particles also optimize object density. ASTM International continues to work toward standardizing specifications for AM metal powders. Powder Metals are typically spherical shaped to ensure good flow/coating ability and a high packing density Particle size is usually below 50 µm or 150 µm depending on machine type and surface finish or productivity required, particle size distribution tailored to the application and properties, controlled chemical composition and gas content. The most common materials for laser melting processes are shown in the table opposite. The material trade names vary depending on the manufacturer, therefore the name used here corresponds to the specifications on the material data sheets and, in some cases, the European nomination is given.

	Material	DIN
Aluminium Alloys	AlSi10Mg	3.2381
	AlSi7Mg	3.2371
	AlSi12	3.3581
Cobalt Based Alloys	ASTM F75	2.4723
	CoCrWC	
Tool Steels	AISI 420	1.2083
	Marage 300	1.2709
	H13	1.2344
	AISI D2	1.2379
	AISI A2	1.2363
	AISI S7	1.2357
Nickel Based Alloys	Inconel 718	2.4668
	Inconel 625	2.4856
	Inconel 713	2.4670
	Inconel 738	
	Hastelloy X	2.4665
Stainless Steels	SS 304	1.4301
	SS 316 L	1.4404
	SS 410	1.4006
	SS 440	1.4110
	15-5 PH	1.4540
	17-4 PH	1.4542
Titanium Alloys	Titanium Grade 2	3.7035

Fig. 1 List of common metal additive manufacturing materials.

III. METAL ADDITIVE PROCESSES

There are a number of different technologies used in the metal Additive Manufacturing systems available today. Systems can be classified by the energy source or the way the material is being joined, for example using a binder, laser, heated nozzle etc. Classification is also possible by the group of materials being processed, such as plastics, metals or ceramics. The feedstock state, with the most common ones being solid (powder, wire or sheet) or liquid, is also used to define the process. Some of the main methods are:

1. Laser-Based Powder Bed Additive

The process of melting and fusing powder together using a laser electron beam.

- Direct metal laser sintering
- Selective laser melting
- Electron beam melting

2. Metal Jetting Technology

The process of building a part layer-by-layer by solidifying photosensitive material.

- Directed Energy Deposition
- 3D Printing with Metal Injection Moulding Powders

3. Furnace-Infused Alloy

The process of joining powder particles via a liquid binding agent.

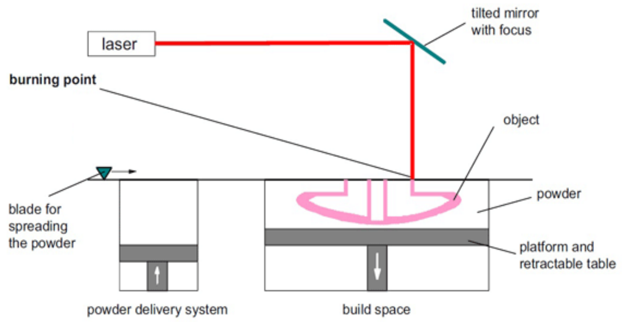

Fig. 2. Schematic diagram of the Selective Laser Melting (SLM) powder-bed process.

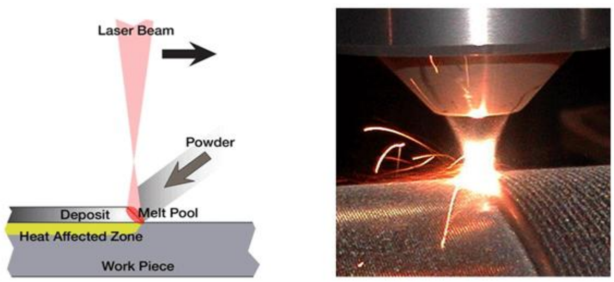

Fig. 3. Schematic of the laser cladding process (Courtesy Sulzer Ltd) and the laser cladding process in action (right).

Almost every powder-bed based AM system uses a powder deposition method consisting of a coating mechanism to spread a powder layer onto a substrate plate and a powder reservoir.

IV. DESIGN ADVANTAGES OF METAL ADDITIVE MANUFACTURING

Until recently the outer geometry of a part and its function and/or strength were of main interest for the user, but Additive Manufacturing allows the integration of additional functions and new fields of application of technical parts. One example of the ability of AM technology to integrate functionality directly into parts is in the production of moulds or tools with conformal temperature control or vacuum channels running directly below the surface of the die. An example of an extrusion tool design with this feature is described in this case study. The cooling channels in this tool cannot be produced with any other technique.

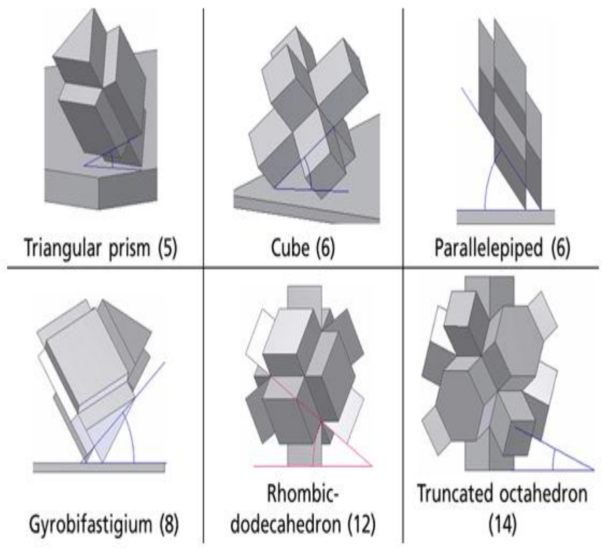

Fig. 4. Basic cell geometries for structure design.

Another good example of using AM to integrate functionality can be seen in parts with repeating internal patterns which enlarge inner surfaces for a better energy or mass exchange in devices for heat recovery or filtration. Some examples of unit cells for 3D tessellation are showed above. These structures make possible the complete filling of the space, if needed, allowing the free design of part density.

V. AEROSPACE APPLICATION

NASA's Perseverance rover, which is scheduled to land on Mars on February 18, 2021, as part of the Mars 2020 mission, will reportedly carry eleven metal additively manufactured parts. The Mars 2020 mission is part of a larger programme that includes missions to the Moon as a way to prepare for human exploration of Mars. Charged with returning astronauts to the Moon by 2024, NASA will establish a sustained human presence on and around the Moon by 2028 through NASA's Artemis lunar exploration plans.

A key objective of Perseverance's mission on Mars is astrobiology, including the search for signs of ancient microbial life. The rover will characterise the planet's geology and past climate, paving the way for human exploration of Mars, and will be the first mission to collect and cache Martian rock and regolith (broken rock and dust). Andre Pate, the group lead for Additive Manufacturing at NASA's Jet Propulsion Laboratory in Southern California, commented, "Flying these parts to Mars is a huge milestone that opens the door a little more for Additive Manufacturing in the space industry."

NASA explains that Curiosity, Perseverance's predecessor, was the first mission to take Additive Manufacturing to Mars when it landed in 2012 with an additively manufactured ceramic part inside the rover's oven-like Sample Analysis at Mars (SAM) instrument. NASA has since continued to test AM for use in spacecraft to ensure the reliability of the parts is well understood.

NASA's Jet Propulsion Laboratory (JPL) is managed by Caltech in Pasadena, Southern California, which built and manages operations of the Perseverance and Curiosity rovers. Of the eleven metal additively manufactured parts travelling to Mars, five are contained within Perseverance's Planetary Instrument for X-ray Lithochemistry (PIXL). This lunchbox-size device is said to help the rover seek out signs of fossilised microbial life by aiming X-ray beams at rock surfaces to analyse them.

1. Advancing rocket propulsion through Additive Manufacturing:

Whilst Additive Manufacturing is undoubtedly having a huge impact on the design and manufacture of rocket propulsion systems, most notably combustion chambers and nozzles, the Achilles' heel of most AM processes is as-built surface finish. Whilst in many AM applications surface finish may be largely irrelevant to a component's function or performance, when it comes to high-cycle fatigue properties, achieving the required level of smoothness is critical to performance. In this article, Justin Michaud, REM Surface Engineering, reports on advancements achieved in this area through a public-private partnership with NASA.

2. Typical applications for metal Additive Manufacturing:
Production of models and prototypes during a product's development phase. Parts for pilot series production in medical, automotive and aerospace industry. Short series production where tooling costs for casting or injection moulding would be too high. Parts of high geometrical complexity which cannot be produced by means of conventional manufacturing (moulding, grinding, milling, casting, etc.)

VI. CONCLUSION

The outstanding feature of all AM techniques is their capability to produce parts of high geometrical complexity which cannot be manufactured by any other production technique. This works because of the tool-free layer-by-layer approach of all AM processes. Parts are produced based on 3D-CAD-model-data without any tooling needed.

The number of available materials is still limited compared to other processes such as milling or injection molding, but the number of materials qualified for polymer and metal-based processes is growing. Many AM techniques offer part qualities which are comparable to those resulting from conventional manufacturing methods. The AM produced parts can be used and post processed (milled, drilled, coated) like any other standard industrial part. Especially in metal, AM produced parts often exceed some of the mechanical property values of those machined from standard bulk material.

Another benefit is the outstanding material efficiency of most AM processes. Scrap rates for AM parts are usually below 5%, compared to scrap rates of more than 90% with many complex milled parts. With a decline in available raw material and rising costs this material efficiency will remain a major advantage in the long term. Looking to the future, it can be confidently predicted that AM is set to achieve an increasing market share of production processes, helped with the introduction of faster systems with more powerful lasers and larger building chambers. A significant number of materials will be qualified for AM and over time multi-material systems for many of the processes will become available.

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