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A Critical Overview of Metal Additive Manufacturing

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Introduction

Additive manufacturing (AM), also known as 3D-printing, is the process by which material is built up, using a layering method to create a 3D part. In 2020, the AM sector produced over $11 billion worth of product. AM presents an advantage over conventional manufacturing (CM) processes (milling, turning, etc.) when making custom one-off or low volume parts. AM allows for complex geometries, such as internal geometries, to be built into a monolithic part at tolerances of 0.05 mm, directly after build completion.

Figure 1: A gas emissions rake developed using AM. Fine internal geometries make the part light weight. The small tubes inside of the part allow gas to flow through the monolithic part. Figure from [1] Richter, T. 2015, “Metal Additive Manufacturing: Component Design for Successful Commercial Production,” Metal AM, 1 (1), pp. 37-45.

Uses

Metal AM is being used in the automotive, aerospace, and medical industries. Across these industries, topographical optimization is being used to create lightweight parts, such as the brake caliper seen in Figure 2. AM in the medical industry is used to create patient specific medical implants and surgical tools.

Figure 2: A brake caliper manufactured via additively manufactured Ti-6Al-4V by Bugatti. The caliper is featured in the Bugatti Chiron super car. Figure from [2] Molsheim and Wolfsburg, 2018, “World Premiere: Brake Caliper From 3-D Printer,” https://www.bugatti.com/media/news/2018/world-premiere-brake-caliper-from-3-d-printer/.

Processes

Powder Bed Fusion	Material Deposition
Sintering and melting processes	Direct energy deposition (DED) and cold spray
Powder feedstock	Powder or wire feedstock
Laser or electron beam energy source	Laser or electron beam energy source for DED
Build bed is filled with powder that is selectively sintered or melted	Cold spray uses Supersonic impingement
Note: Sintering implies incomplete melting of the feedstock	Material is deposited through a nozzle upon a build bed

Areas of Ongoing Research

The metallic material systems available for AM are limited. Research and development is required to bring new material systems to AM. Prior to post processing, metal AM parts do not have the same mechanical properties as bulk materials. This is due to the columnar microstructure of AM parts (Figure 3). Further research into the transition from a columnar to equiaxed grain structure in the context of AM could make this possible. AM is known as low waste but in powder processes some powder is disposed of. Powder recycling is a field in which more research and development are required.

Figure 3: A light optical microscopy image of the grain structure of an Inconel 625 made cylinder made via electron beam melting. The highly oriented columnar microstructure runs parallel to the build direction shown by arrow “B”. Figure from [3] Murr, L., Martinez, E., Amato, K., Gaytan, S., Hernandez, J., Ramirez, D., Shindo, P., Medina, F., and Wicker, R., 2012, “Fabrication of Metal and Alloy Components by Additive Manufacturing: Examples of 3D Material Science,” Journal of Materials Research and Technology, **1**(1), pp. 42-54.

References:
[1] Richter, T. 2015, “Metal Additive Manufacturing: Component Design for Successful Commercial Production,” Metal AM, **1** (1), pp. 37-45.
[2] Molsheim and Wolfsburg, 2018, “World Premiere: Brake Caliper From 3-D Printer,” https://www.bugatti.com/media/news/2018/world-premiere-brake-caliper-from-3-d-printer/.
[3] Murr, L., Martinez, E., Amato, K., Gaytan, S., Hernandez, J., Ramirez, D., Shindo, P., Medina, F., and Wicker, R., 2012, “Fabrication of Metal and Alloy Components by Additive Manufacturing: Examples of 3D Material Science,” Journal of Materials Research and Technology, **1**(1), pp. 42-54.

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