11º Workshop em Engenharia e Tecnologia Espaciais
18, 19 e 20 de agosto de 2020

Additive Manufacturing, its applications in the Space Industry and opportunities for National Institute for Space Research (INPE)

Anderson Luis Barbosa[1], Maria do Carmo de Andrade Nono[2], Daniel Alessander Nono[3]

[1]Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brasil

Masters Student in Science and Technology of Materials and Sensors - CMS.

[2]Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brasil

Micro and Nanotechnology of Ceramics and Composites / Associated Laboratory of Materials and Sensors

[3]Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brasil

Ph.D. Candidate in Science and Technology of Materials and Sensors - CMS.

`albarbosa92@gmail.com`

Abstract. *Additive Manufacturing (AM) is a huge change in fabrication and production paradigms. AM is being adopted by diverse industries due to its many advantages, such as facilitating the production of complex shapes and customized products. In the space industry, most of the products are specific and customized, which makes AM highly viable and interesting for this industry. Also, AM allows new ways of thinking the fabrication, which opens opportunities for new and revolutionary designs. Thus, AM can bring many new opportunities and advantages for the National Institute for Space Research (INPE) in Brazil.*

Keywords: Additive Manufacturing; 3D Printing; Space Industry; Space Components.

1. Introduction

Additive Manufacturing (AM), also known as 3D printing according to Gao et al (2015), is defined by the American Society for Testing and Materials (ASTM) in its designation F2792 − 12a from 2013 as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies”. Chen et al (2019) say that AM is a philosophy that permits the fabrication of structures that are not possible to reach through traditional fabrication, due to the complexity and precision of the structure. The first record of a technology that uses this method of fabrication is by Charles Hull in 1986, with a process called stereolithography (SLA) and, since then, many other processes were developed (NGO et al, 2018).

2. Advantages and Disadvantages

AM has unique features that distinguish it from the traditional manufacturing process, which grant diverse advantage for fabrication in several aspects; however, some disadvantages must be acknowledged.

Gao et al (2015) explained that the layer-by-layer process allows the fabrication of most of the shapes despite the complexity it has, which contrasts with the subtractive processes. The flexibility of the design and fabrication also allows the weight reduction through the hollowing of the objects, losing little or none of its mechanical properties compared to a solid piece. Therefore, AM significantly reduces the use and the waste of material (CALIGNANO et al. 2017; GAO et al, 2015; NGO et al, 2018).

When using AM technologies, the change of design and the increase of complexity does not affect the production cost, since that there is no need for new tooling, no changes in the setup, or additional training for the operators, which allows the mass-customization of the products (GAO et al, 2015; NGO et al, 2018).

AM allows the fabrication of shapes that, otherwise, would demand assemblage of multiple parts. It can occur in the following ways: fabricating one solid shape or fabricating a product with moveable parts already integrated as a “single-part assembly” (GAO et al, 2015).

Also, according to Gao et al (2015), AM can be time and cost-efficient, compared to traditional methods, in low quantities of production.

Calignano et al. (2017, p. 594) affirm that, due to this characteristic, AM enables "rapid response to markets as the possibility to produce on demand the spare parts, reducing or eliminating the need for stockpiles."

Even with the advantages that AM provides, its disadvantages must be considered. Due to its fabrication approach, the products present a layer-by-layer appearance, which can be an issue for some applications (NGO et al, 2018). Though it can be possible, in some cases, to apply post-processing to address this layer-by-layer appearance issue, it will increase the cost and the production time (GAO et al, 2015). Another concern is the anisotropic microstructure and mechanical properties, due to the layer-by-layer nature of AM, which can make the mechanical properties of the printed product vary in different orientations (NGO et al, 2018).

The problems mentioned above can be overcome with new researches and technologies, and the development of new materials and methods for AM (GAO et al, 2015; NGO et al, 2018).

3. AM Techniques

Since the first AM technology was developed in 1986, many others have been created (NGO et al, 2018). There is an extensive list of AM technologies, however, the ASTM F2792 − 12a (2013) defines 7 categories that groups those technologies, as follow:

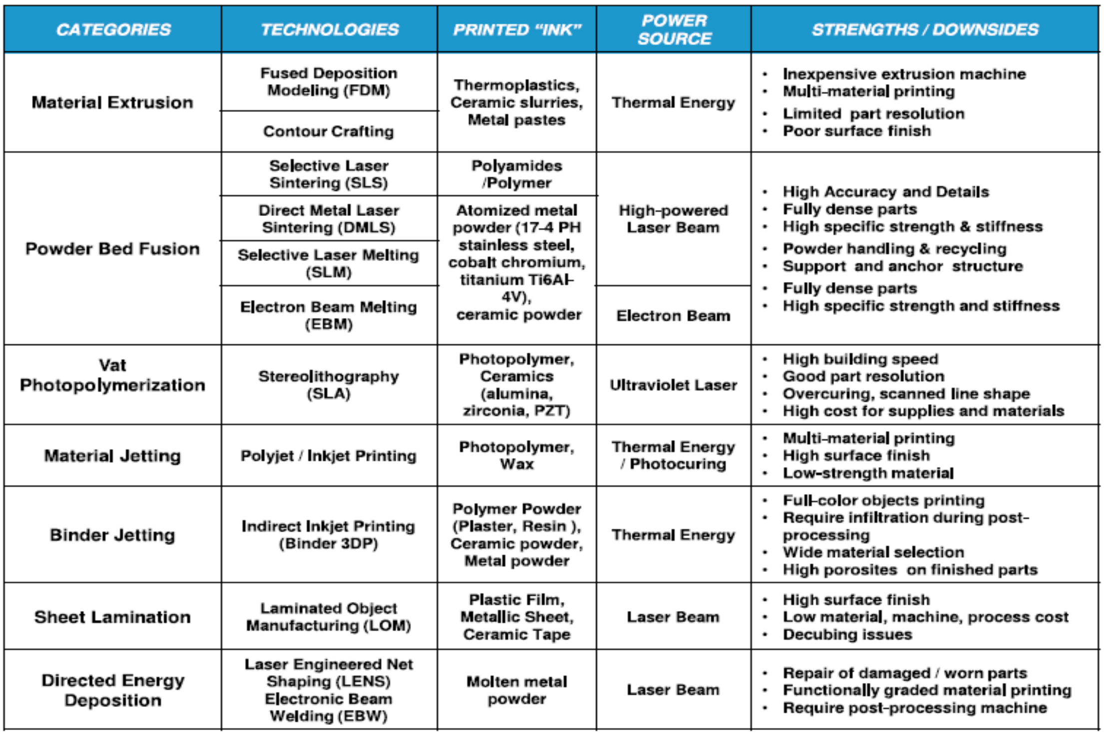
- **binder jetting,** n—an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials.
- **directed energy deposition**, n—an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as

they are being deposited. DISCUSSION—Focused thermal energy means that an energy source (e.g., laser, electron beam, or plasma arc) is focused to melt the materials being deposited.

- **material extrusion**, n—an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice.
- **material jetting**, n—an additive manufacturing process in which droplets of build material are selectively deposited. DISCUSSION—Example materials include photopolymer and wax.
- **powder bed fusion, n**—an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed.
- **sheet lamination**, n—an additive manufacturing process in which sheets of material are bonded to form an object.
- **vat photopolymerization**, n—an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization. (ASTM, 2013)

Table 1 shows the categories above describe, with some examples of technologies for each category, as well as the “ink” that is used, the power source, and its strengths and downsides (which are related more specifically to each category).

Table 1 - Classification of additive manufacturing processes by ASTM International



CATEGORIES	TECHNOLOGIES	PRINTED “INK”	POWER SOURCE	STRENGTHS / DOWNSIDES
Material Extrusion	Fused Deposition Modeling (FDM)	Thermoplastics, Ceramic slurries, Metal pastes	Thermal Energy	• Inexpensive extrusion machine • Multi-material printing • Limited part resolution • Poor surface finish
	Contour Crafting			
Powder Bed Fusion	Selective Laser Sintering (SLS)	Polyamides /Polymer	High-powered Laser Beam	• High Accuracy and Details • Fully dense parts • High specific strength & stiffness • Powder handling & recycling • Support and anchor structure • Fully dense parts • High specific strength and stiffness
	Direct Metal Laser Sintering (DMLS)	Atomized metal powder (17-4 PH stainless steel, cobalt chromium, titanium Ti6Al-4V), ceramic powder		
	Selective Laser Melting (SLM)			
	Electron Beam Melting (EBM)		Electron Beam	
Vat Photopolymerization	Stereolithography (SLA)	Photopolymer, Ceramics (alumina, zirconia, PZT)	Ultraviolet Laser	• High building speed • Good part resolution • Overcuring, scanned line shape • High cost for supplies and materials
Material Jetting	Polyjet / Inkjet Printing	Photopolymer, Wax	Thermal Energy / Photocuring	• Multi-material printing • High surface finish • Low-strength material
Binder Jetting	Indirect Inkjet Printing (Binder 3DP)	Polymer Powder (Plaster, Resin), Ceramic powder, Metal powder	Thermal Energy	• Full-color objects printing • Require infiltration during post-processing • Wide material selection • High porosites on finished parts
Sheet Lamination	Laminated Object Manufacturing (LOM)	Plastic Film, Metallic Sheet, Ceramic Tape	Laser Beam	• High surface finish • Low material, machine, process cost • Decubing issues
Directed Energy Deposition	Laser Engineered Net Shaping (LENS) Electronic Beam Welding (EBW)	Molten metal powder	Laser Beam	• Repair of damaged / worn parts • Functionally graded material printing • Require post-processing machine

Source: GAO et al. (2015)

4. Materials in AM

Currently, a limited number of materials are available for applications in AM, which can be a challenge in some industries, however, materials for AM is a wide field in development (NGO et al, 2018).

AM permits and facilitates novel ways to use materials, combining materials properties, geometry, and other properties that can be achieved by the process. With AM, it is possible to print pieces that have a different density or grain size in each region, as well as different material compositions, basically engineering the properties of the material by combining their distribution (GAO et al, 2015).

AM of metal has an excellent perspective in the growth of use and applications, being applied mostly for research, prototyping, and advanced applications, such as aerospace industry, biomedical parts, and automotive industry. The AM process for metals consists, basically, of the melting of the metal fed as wire or powder using a laser or electron beam (NGO et al, 2018).

Polymers are the most common material used for printing since it is easy to apply in diverse AM process. Polymers are generally used for prototyping but can be found in final products too, and it is used in many industries, such as aerospace, medical application, and toy fabrication. Polymers are used in the form of thermoplastic filaments, reactive monomers, resin, or powder. It is possible to print polymers with fibers or other additives, making a composite that can enhance the mechanical properties of the material (NGO et al, 2018).

The use of AM for fabricating ceramics unveils great new perspectives for the application of this material, mainly for advanced ceramics. AM can address the main problems of the fabrication of ceramic components, like the difficult to build complex shapes, since it can be hard to build complex molds for the green body of ceramic, and, in the case of the sintered body, it is tough to machine the piece, for ceramics are, generally speaking, hard and brittle materials. 3D printed ceramics can be applied in a wide range of products, like sensors, space and aerospace components, orthopedic and dental parts, and much more. The AM process for ceramics can be classified in slurry-based, powder-based, and bulk solid-based methods (CHEN et al. 2019).

5. AM in the Space Industry

According to Sacco and Moon (2019, p. 1), the space industry is “a sector that is poised to greatly benefit from AM”, since most of the components of this industry are custom made. AM can provide the lowering of the mass of the components from 40 to 90%, which is certainly relevant, since the costs of a rocket launch are proportional to the mass being launched, and AM can also shorten the time of production of a complex part, compared to traditional manufacturing (CALIGNANO et al. 2017; SACCO; MOON, 2019, p. 1).

Sacco and Moon (2019) also point the advantages for In Space Additive Manufacturing (ISAM), which address the fabrication in space and other space objects, such as the Moon and Mars. With ISAM, the costs of a space mission can be reduced by fabricating what is necessary already in space, launching only the raw material and the components necessary, and, in the case objects, it is possible to use regolith (which is how lunar soil is called and can be also used for Martian soil) as raw material, is only required the launch and installation of the 3D printers.

Some of the recent applications of AM in the Space Industry will be presented next, but it is needed to make clear that some of the uses were only announced in news and as of press release, since they are Trade Secrets, or for reasons of safety demanded by some regulations.

Ngo et al (2018) reported the first advanced “Ariane 6 nozzle (SWAM)” was developed using AM by GKN Aerospace for the Airbus Safran Launchers’ “Vulcan 2.1” engine; a company called Arconic manufactured using AM the NASA's SLS/Orion spacecraft vents; “NASA printed 70 components of the Mars rover using Stratasys FDM technologies to obtain a lightweight and strong structure”

According to Daniel (2019), in an article entitled "Additive manufacturing in space: How NASA's 3D printing could transform spacecraft building", National Aeronautics and Space Administration (NASA) is using AM to produce parts for spaceships and also to build tools for their space missions.

Jackson (2019) reported that the “European Space Agency (ESA) has completed the first hot fire testing of a full scale, 3D printed rocket engine demonstrator named BERTA”

NASA has a page in its website entitled “In-Space Manufacturing” which presents their projects for In Space Manufacturing, which includes the use of AM ("In-Space Manufacturing", 2019).

ESA also have an article on its website that exposes their interest and the benefits of AM for space applications ("Advanced Manufacturing", 2020).

6. Conclusion

A wide range of opportunities can be explored with the implementation of AM at INPE in the processes of satellite development. Despite being a relatively expensive initial investment and being a paradigm shift for many scientists and engineers, there are significant advantages to invest in AM, like:

a. Build prototypes in-house;

b. Build components in-house, such as structural pieces, circuit boards, electronics, sensors, and much more;

c. Develop customized tools to use in Assembly, Integration, and Tests (AIT);

d. Speed up the process of projecting and building of nanosatellites, by making components and prototypes at the institute, instead of outsourcing these activities;

e. Savings in manufacture processes;

f. Savings in production time;

g. Savings in AIT processes time;

h. Capability to produce complex geometries;

i. Capability to meet the requirements and specifications with accuracy;

j. The capability to change the design of parts in short times.

Considering the characteristics and advantages pointed in this paper, the use of AM can be remarkably beneficial for INPE in diverse areas and applications.

Acknowledgments: *This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.*

References

Advanced Manufacturing. Available on: <https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Advanced_Manufacturing>. Visited in: 6 Jul. 2020.

AMERICAN SOCIETY FOR TESTING AND MATERIALS. F2792 − 12a: Standard Terminology for Additive Manufacturing Technologies. West Conshohocken: ASTM International, 2013. Visited in: 9 Jun. 2020.

CALIGNANO, F. et al. Overview on Additive Manufacturing Technologies. Proceedings of the IEEE, v. 105, n. 4, p. 593-612, 2017.

CHEN, Z. et al. 3D printing of ceramics: A review. Journal of the European Ceramic Society, v. 39, n. 4, p. 661-687, 2019.

DANIEL, E. How NASA additive manufacturing could transform spacecraft building. Available on: <https://www.verdict.co.uk/nasa-additive-manufacturing/>. Visited in: 6 Jul. 2020.

GAO, W. et al. The status, challenges, and future of additive manufacturing in engineering. Computer-Aided Design, v. 69, p. 65-89, 2015.

In-Space Manufacturing. Available on: <https://www.nasa.gov/oem/inspacemanufacturing>. Visited in: 6 Jul. 2020.

JACKSON, B. ESA completes first test fire of ArianeGroup 3D printed rocket engine - 3D Printing Industry. Available on: <https://3dprintingindustry.com/news/esa-completes-first-test-fire-of-arianegroup-3d-printed-rocket-engine-149737/>. Visited in: 6 Jul. 2020.

NGO, T. et al. Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. Composites Part B: Engineering, v. 143, p. 172-196, 2018.

SACCO, E.; MOON, S. Additive manufacturing for space: status and promises. The International Journal of Advanced Manufacturing Technology, v. 105, n. 10, p. 4123-4146, 2019.