

Research Proposal

Additive Manufacturing (AM) and Subtractive Manufacturing (SM)

Application and advantages of Additive Manufacturing and Subtractive Manufacturing

MSc International Innovation Management (IIM)

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Introduction

Traditional or conventional manufacturing processes falling into two main categories namely formative which includes injection moulding, die casting etc. and subtractive which includes milling, grinding, CNC machining etc. and they have dominated the manufacturing market, manufacturing activities in supply chain for decades (Jimo et al., 2019, p. 766).

It includes several process, different material, machines, tools, etc. And it gives great accuracy in parts. In subtractive manufacturing we removed material from part to give the final and accurate shape of that part or product.

There is one more technology or manufacturing method, Additive manufacturing (AM) seems new to many, it has actually been using in many industries for several decades. In the right application with right material and process additive manufacturing gives a perfect trifecta of improved performance, complex geometries and simplified fabrication (GE additive, n.d.).

For many years, no one considered additive manufacturing as a scalable method for high-volume production because older 3D printing systems did not offer high production, had poor surface finishing, and poor material properties. Today's advanced 3D printing solutions with advanced materials, faster speed, and higher throughput allow companies to take a hybrid or fully additive manufacturing approach (LuxCreo, 2021).

Highlights (Aims and Objective) of this documents

3D printers are old technology and were born commercially in the mid to late 1980s and heavily leveraged foundational technologies including computer "CNC" control, 2D printing, and laser development. In the 1990s many foundational principles of AM were developed, improved, patented, and commercialized. By the 2000s, AM technologies had matured and were being adopted primarily for commercial prototyping. In the 2010s, the foundational patents for most of the original 3D printing methods expired and a new wave of interest and resources expanded the industry (LuxCreo, 2021).

Additive manufacturing (3D printing) is 40-50 years old technology and previously it was only noticed for prototyping but now days it can be seen in actual manufacturing (end use parts) with all other industries. We can say that AM is parallelly using with subtractive manufacturing. This document will highlight,

- What is additive manufacturing?
- Additive manufacturing methods/processes
- List of different process in Additive Manufacturing
- Materials for Additive Manufacturing
- Applications of Additive Manufacturing
- Advantages and disadvantages of Additive Manufacturing
- Subtractive Manufacturing
- Types of Subtractive Manufacturing Process
- Application of Subtractive Manufacturing
- Advantages and disadvantages of Subtractive Manufacturing
- Key Differences between Additive and Subtractive Manufacturing

What is Additive Manufacturing?

The ASTM International Committee F42 on AM technologies defines AM as the “process of joining materials to make objects from three-dimensional (3D) model data, usually layer by layer, as opposed to subtractive manufacturing methodologies (Huang et al., 2015, p. 2).

Additive manufacturing (AM) can be described as a technique of blending materials by either fusion, binding, or solidifying materials such as liquid resin and powders. It builds part in a layer-by-layer fashion using 3D CAD modelling. The terminologies such as 3D printing (3DP), rapid prototyping (RP), direct digital manufacturing (DDM), rapid manufacturing (RM), and solid freeform fabrication (SFF) can be used to describe AM processes (Abdulhameed et al., 2019, p. 2).

Additive manufacturing methods/processes

There are so many processes available for additive manufacturing. They are different from each other particularly in the way layers are lay down to manufacture a part or item. And those processes are also depend on material and so operating principles are also different from each other.

Some methods or processes use the material in liquid state. So to produce the layers, material need to be melted or softened before, for instances, selective laser melting (SLM), selective laser sintering (SLS) and fused deposition modelling (FDM), While in other processes liquid material need to be cured, for an instance, stereolithography (SLA).

All these processes have its own advantages and drawbacks, company can choose their process as per the material of the product.

❖ Laser based process-

➤ Laser polymerization-

- Stereolithography (SLA)
- Solid ground curing (SGC)
- Liquid thermal polymerization (LTP)
- Beam interference solidification (BIS)
- Holographic interference solidification (HIS)

➤ Laser melting-

- Selective laser sintering (SLS)
- Selective laser melting (SLM)
- Direct metal laser sintering (DMLS)
- Laser engineered net shaping (LENS)
- Direct metal deposition (DMD)
- Laser powder deposition (LPD)
- Selective laser cladding (SLC)

➤ Extrusion processes

- Fused deposition modelling (FDM)
- Robocasting

➤ Material jetting

- Three-dimensional printing (3DP)

- Inkjet printing (IJP)
 - Multijet modelling (MJM)
 - Ballistic particle manufacturing (BPM)
 - Thermojet
- **Adhesive**
- Laminated object manufacturing (LOM)
 - Solid foil polymerization (SFP)
 -
- **Electron beam**
- **Electron beam manufacturing (EBM)**

Table 1 Additive manufacturing process categorization

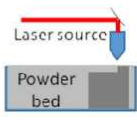
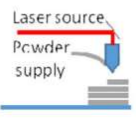
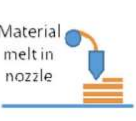
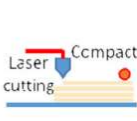
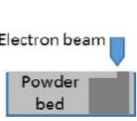
Additive Manufacturing (AM) Processes														
Process	Laser Based AM Processes						Extrusion Thermal	Material Jetting	Material Adhesion	Electron Beam				
	Laser Melting		Laser Polymerization											
Process Schematic														
Name Material	SLS		DMD		SLA		FDM		3DP		LOM		EBM	
	SLM		LENS		SGC		Robocasting		IJP		SFP			
	DMLS		SLC		LTP				MJM					
			LPD		BIS				BPM					
					HIS				Thermojet					
Bulk Material Type		Powder		Liquid		Solid								

Table 1 Additive manufacturing process categorization (Bikas, Stavropoulos and Chryssolouris, 2015)

Materials for Additive Manufacturing

There are variety of materials listed in the AM application and research for future development of new material is in progress.

We can find main 3 types of material in AM i.e. polymer, ceramic and metals. All individual AM processes, cover the use of these materials, although polymers are most commonly used and some additive techniques lend themselves towards the use of certain materials over others (Singh, Ramakrishna and Singh, 2017, p. 2-3).

Today, various categories of biomedical materials are available with us in-terms of metals, alloys, ceramics, bioactive glass, plastics and their combinations. Table.1 illustrates the category of material allotted to various AM techniques. Metals have been used for implant manufacturing since more than 120 years ago. During early development, corrosion and insufficient strength problems were faced, however, after the introduction of the stainless steel (SS) in 1920, superior corrosion resistance properties attracted clinical interest. In the recent past, along with SS-316L, Ti and Co–Cr–Mo alloys, various polymers, glass and ceramic materials found their applications as an implant material different type of biomedical material (Singh, Ramakrishna and Singh, 2017, p. 2-3).

- Alloys of aluminium and magnesium
- Alloys of titanium
- Steels in AM
- Ceramics
- Stainless steel AISI316
- CrNi-Steel
- Special materials
- Smart materials
- Shape-Memory alloy (SMA)
- Shape-Memory polymer (SMP)
- Piezoelectric material
- Biomaterials (Medical application of 3D printing)

Applications of Additive Manufacturing

Lightweight Machines- with AM we can manufacture lightweight machine parts. Lightweight parts are really important and considered in the automobile and aerospace industries. For those industries, main aim is lightweight parts by securing the safety (Wong and Hernandez, 2012, p. 5-6).

Architectural Modelling-

Creating an architectural model can be very difficult for architects. Additive manufacturing technologies is very powerful tool for architects and their business development, by being able to create a physical model faster without worrying about the complexity of their design. It also achieves a better resolution than other processes used in architecture. Architects work with CAD software, so there is no need for them to adapt to anything because the STL file is created from a CAD file (Wong and Hernandez, 2012, p. 5-6).

Medical Applications-

Additive manufacturing printing technologies have vast applications in the medical world. The medical industry is one of the largest users of AM. This is the one of the industries where additive manufacturing's twin advantages of complex part design freedom and personalisation can really be utilised. The medical industry is also the industry where some of the more cutting edge and ground breaking uses for additive manufacturing are taking place and being researched (manufacturingtomorrow.com, n.d.).

Improving the Manufacturing of Fuel Cells-

Additive manufacturing technologies can be used in processes that require a very precise thin film of a certain material. In the manufacture of polymer electrolyte membrane fuel cells (PEMFCs), it is necessary to precisely deposit a very thin layer of platinum, needed for the oxidation and reduction reactions, with high utilization efficiency of the platinum. This could be critical for taking this technology to the masses (Wong and Hernandez, 2012, p. 5-6)..

Additive Manufacturing in Art.

Additive manufacturing technologies are a very powerful tool to artist in the fashion, furniture, and lightning industry given the possibility of virtually manufacturing the most complex form imaginable. There are companies that manufacture furnishing complements, lightning, and accessories including clothes using SLS (Wong and Hernandez, 2012, p. 5-6).

Manufacturing industries-

Most of the industries have been using AM parts for prototyping. Additive manufacturing has become a valuable asset also in the world of prototyping owing to its ability to quickly and affordably craft a functional 3D representation of a product concept. This technology enables creators to test product functionality—for

example, the ability for parts to interlock, fasten, or snap—as well as to evaluate product features such as the amount of stress a part can take, the durability of a given material, the functionality of microscale features, and physical dimensions. In other words, additive manufacturing provides companies the opportunity to experiment with and inspect the fine details of a given product in a more time- and cost-efficient manner than older techniques such as product prototype machining, injection moulding, and casting allow (PRG Prototyping, n.d.).

Advantages and disadvantages of Additive Manufacturing

Some advantages of additive manufacturing are listed below (rapiddirect, 2022)

- Highly efficient and reduce or eliminates waste
- Faster route from design to production-whole process will be quick
- Create complex designs easily-Best for the complex

Some disadvantages of additive manufacturing are listed below (rapiddirect, 2022)

- Has a limited range of materials compared to other processes-limited material choice
- It can be expensive when it involves the use of metals
- Not ideal for large quantity production-Can't use with mass production

Subtractive Manufacturing

Subtractive manufacturing, as the name it self-explains, starts from a bulk piece and continually removes material through processes like drilling, milling, turning until reaching the desired shape. Contrary to manually controlled systems through levers or hand wheels, the subtractive machine, also known as CNC (Computer Numerical Control) machine, is an automated machine that follows a program of instructions, known as the G-code (Acsinte, 2019, p. 27).

Furthermore, this manufacturing technology allows designing, prototyping, and manufacturing in end-use materials. It is also the perfect option for small and big volume productions to get specific mechanical properties or finishes. It works with metals or resin-like aluminum, brass, ABS, Delrin, Nylon, PEEK, PVC, plexiglass, PCA, Polypropylene, as well as wood.

Additionally, it is easier to match the design in subtractive manufacturing techniques with material for strength, flexibility, chemical resistance, or other dielectric properties.

Types of Subtractive Manufacturing Process

The common types of subtractive manufacturing include cutting, machining, and abrading.

Application of Subtractive Manufacturing

Fabricating contoured profiles and textured surfaces.

Cutting various features that are useful in household applications as well as automobile, aerospace, electronics, dental and medical requirements (Minaprem.com, n.d.).

Advantages and disadvantages of Subtractive Manufacturing

Some advantages of additive manufacturing are listed below (rapiddirect, 2022)

- We can use various materials like metal, plastic, wood, and composites

- Shapes flexibility-Used for all shapes like holes, cylinders, screw threads, or flat surface
- Accurate finishing-Ideal for obtaining a smooth surface
- Produces high accuracy with 0.0025 mm close tolerance

Some disadvantages of additive manufacturing are listed below (rapiddirect, 2022)

- High waste- Wastes material and chips formed. The chips are recyclable though but are still waste.
- Long process time -It takes more time than additive manufacturing

Key Differences between Additive and Subtractive Manufacturing

Additive and subtractive technologies come in many form factors, with a range of cost and capabilities, from desktop machines to large industrial equipment. Ultimately, you should choose the technology that makes the most sense for your business needs and applications (Formlabs, n.d.).

	Additive Manufacturing	Subtractive Manufacturing
Material Options	Works with a narrow range of materials, mostly plastic, plastic derivatives, biochemical, resin, and some metals	It uses a wider range of materials, including; stone, glass, wood, foam, metals, and plastics
Equipment Costs	Professional desktop printers start at \$3,500 for plastics. Large-scale industrial machines for metals start from ~\$400,000.	Small CNC machines for workshops start around \$2,000. More advanced workshop tools go well beyond that depending on the number of axes, features, part size, and tooling needed for specific materials.
Achievable Complexity	Better than 5-axis CNC machining in the development of complex and intricate designs	Ideal for use with simple geometry
Accuracy	The products produced using this process are less accurate than the traditional process. The most accurate additive manufacturing process has a tolerance level of 0.100mm	It produces products with more dimensional accuracy. With Tolerance levels as tight as 0.025mm
Properties Of Finished Parts	Parts produced using this technique might have structural weaknesses. The reason is that the production occurs through layering, and this compromises some properties	Parts produced have excellent heat resistance and are structurally sound
Surface Finish Choices	Finishing is an important aspect of parts produced using this technique	Finishing is not compulsory for parts produced using this method
Speed	Faster and less costly when the prototype and batch production are small	Faster and less costly when the prototype and batch production are small
Training	Desktop printers are practically plug and play, requiring minor training on build setup, maintenance, machine operation, and finishing. Industrial additive manufacturing systems require dedicated staff and extensive training.	Small CNC machines require moderate training for software, job setup, maintenance, machine operation, and finishing. Larger, industrial subtractive systems require dedicated staff and extensive training.

Facility Requirements	Desktop machines are suitable for the office and benchtop systems for a workshop environment with moderate space. Industrial 3D printers often require a dedicated space or room with HVAC control.	Small CNC machines are suitable for workshops. Industrial systems require a larger, dedicated space.
Ancillary Equipment	Tools and (some automated) systems for cleaning, washing, post-curing, and finishing, depending on the process.	Various tooling. More advanced systems automate some processes like tool changing, chip clearing and handling, and coolant management.

(Rapid Direct, 2022)

Specific Energy Consumption-

AM processes are generally not as efficient as conventional manufacturing processes mainly due to its low processing speed. Basic power consumption and the time it requires to complete a piece are the main considerations in energy consumption (Drizo and Pegna, 2006). Being a layer by layer process, the amount of energy consumed per unit volume of material is higher than other conventional manufacturing processes. Nevertheless, because it allows building more complex geometries and this results in a lighter final piece, it is still a competitive option (Mansour and Hague, 2003).

Repeatability with accuracy-

When comparing subtractive manufacturing over additive manufacturing, one of the advantages of SM is its high accuracy and repeatability, being one of the most used manufacturing processes when facing precision dimensional requirements (Newman, Dhokia, and Shokrani, 2015). The CNC machine is capable of producing the same piece over and over again without flaws (Newman, Dhokia, and Shokrani, 2015). By starting with the same bulk piece of material and feeding the same program to the machine, one can expect the same quality. This is one of the main reasons why additive manufacturing still cannot replace this conventional method (Acsinte, 2019, p. 27).

Size-

Relatively to the size of the produced parts, subtractive manufacturing is better suited to manufacturing large parts. This is an advantage over additive manufacturing where the size of the piece is limited by the build envelope size of the AM machine. The building chamber of the AM machine is enclosed to control the temperature, so a bigger space would also imply a higher energy expenditure (Acsinte, 2019, p. 28).

Additive Vs Subtractive Manufacturing Cost-

Machinery and Tooling Costs

It is really expensive to acquire and install precision additive manufacturing equipment. This makes an investment in machines the highest contributor to additive manufacturing costs.

For additive manufacturing, tooling expenses are accountable for 5% of the total cost of production and are one of the advantages of additive manufacturing over subtractive manufacturing.

Besides, layer-by-layer printing makes the additive manufacturing process very adaptable for different products, thereby saving cost. On the other hand, designing the tool is important for each subtractive manufacturing process.

Labour costs

Due to the highly automated nature of both methods, labour costs account for a small proportion of the total cost. Simplifying parts in both additive and subtractive manufacturing helps reduce labour.

Moreover, simplification involves redesigning a part to reduce the required number of parts. This redesign would also help to reduce production, assembly, and post-processing costs. Generally, labour cost accounts for less than 10% of production costs in additive manufacturing.

Material Costs

Materials used in additive manufacturing often cost higher than those used in subtractive manufacturing.

According to the international cost estimating and analysis association, materials for additive manufacturing are more expensive than those used for subtractive manufacturing by a factor of 8 on a per-weight-basis.

Post processing costs

Manufactured parts often also require post-processing to reach their final state. This often involves washing or polishing to improve the sheen for metal parts. Furthermore, products manufactured additively, especially using the precision mechanical system, involve removing the surplus material.

Above all, post-processing costs are similar for both manufacturing processes and inevitable.

Furthermore, while there are key differences, subtractive and additive manufacturing are not mutually exclusive. In fact, they are quite often used side by side and at different stages of product development and in manufacturing (Formlabs, n.d.).

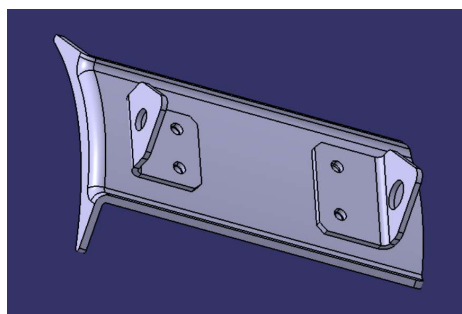
Conclusion-

In terms of economy and sustainability, AM offers multiple advantages over conventional manufacturing techniques. Freedom of design, customisation, ability to print complex structures and minimum waste these are the main benefits of Additive manufacturing over Subtractive Manufacturing. However, there are few downsides such as high cost, limited material/material choice, mass production, limited application in large structures, defects in the product, inferior and anisotropic mechanical properties, all these would require further research and technological development (Ngo et al., 2018).

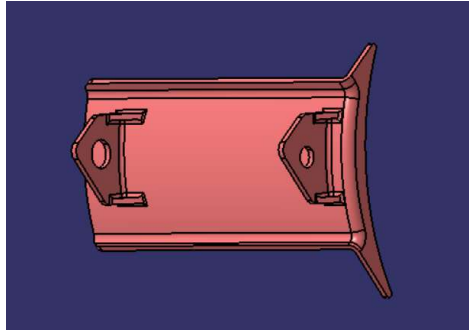
Certainly, additive manufacturing plays good role in aerospace, defence and automobile. As they required light weight and particular shape of the product and AM allows the customization and freedom in design.

Sometimes, it gives better opportunity to manufacture a product in one piece where with conventional or subtractive manufacturing process it might require in 2 or 3 parts attachment in total.

For an instance, if we want design Closeout with specific fixing, we can't change the shape of the part or fixation.



Closeout design for Subtractive manufacturing process- we can see 3 different parts.



The same Closeout design for Additive manufacturing process- we can see the Part consolidation
3 parts can be consolidated into 1 part



The Closeout Additive manufacturing image

From above example, with AM we can reduced the weight with part itself, with fixation fastener, save the manufacturing/operation time, as well as save time while building the assembly. Because of reducing in part numbers, it also reduces engineering work. In this case, we will require only one CAD model to design or create, same for the drawing terminology, we will require only one drawing for this additive manufacturing part. But if we go with Subtractive manufacturing process (as shown in the image above) we will need to create three separate CAD models and then one more assembly CAD model. When we go to create the drawings, we will need create one drawing for each part as well as one more drawing for assembly. So that will be the time consuming process for engineering time. Again when it will go through release process it will consume more time to create workflows and get all those approved. So clearly if we go with more parts that would be the lengthy process.

Similarly, we have seen Additive manufacturing is a bit expensive process in terms of machine cost, time consuming against complex parts and material. However, research team is continuously working on the process, development, and more on the material to find out new material and methods so there will be new options. Additive manufacturing is still evolving, giving it a distinct future advantage. An increasing number of industries is adopting it. This means that the technology will develop to be more economical, iron out its limitations and offer better and newer materials, technologies, and a more sustainable manufacturing approach.

Utilizing both additive and subtractive manufacturing results in a hybrid process. This allows product designers and manufacturers to combine the versatility and quick turnaround times of additive manufacturing with the strength of subtractive produced parts (Formlabs, n.d.).

We have already discussed the drawbacks of AM, from that we can see AM will not replace subtractive and conventional manufacturing methods in the nearer future, especially for the high volume production of

parts with low complexity and high accuracy. However, AM may still bring thoroughgoing progress to the manufacturing industry through its integration with conventional manufacturing technologies (Huang et al., 2015).

Aside from specific use cases, Subtractive and traditional manufacturing is still faster and less expensive. This is especially true when creating granular products. The smaller the layer size, the slower the manufacturing. While the initial units are cheaper and faster when made with additive manufacturing, in the long run, printing out every unit would take longer (MIT Sloan, n.d.).

Additive manufacturing is in fact the best option for parts that present high complexity. For parts with lower complexity, the high material prices increases the total cost and is where subtractive manufacturing becomes a better choice. Even for the same material price, subtractive manufacturing is still the same options for parts with low complexity due to the high energy needs of an additive manufacturing machine (Acsinte, 2019, p. 84).

As additive manufacturing is a rising technology, it will take time for it to be considered a conventional manufacturing process.

In conclusion, both additive and subtractive manufacturing presents a wide range of advantages and disadvantages to one another. When considering which process will be used to produce a part, the importance of part requirements, materials, and design come into question, time requirement/schedule.

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