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A review of the benefits of additive manufacturing for industries

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Abstract

Additive manufacturing which seen as being one of the imperative revolutionary processes in advanced industrial sectors. Additive manufacturing is the solution which facilitates the flexible production of customized products with less impact on costs and fabricating lightweight structures with admirable quality. It is applied in recent industrial revolution and its encouraging the amalgamation of intelligent production systems and advanced information technologies. Additive manufacturing is also known as 3D printing, is a revolutionary technology that has the probable to transform manufacturing by enabling on-demand, independent and customized products. In this paper discussed about the benefits of additive manufacturing processes used in industries.

1. Introduction

Additive manufacturing is a set of production technologies that allows attain a final product through the generation and consequent accumulation of layers of material. Additive manufacturing moves in the contradictory direction compared to conventional production systems that proceed by subtraction. Unlike processes such as milling or turning, additive manufacturing adds the material desirable to create products. As a result, it creates less waste and cuts the resources waste. It includes cost reduction, resource-saving, sustainability, prototype testing, and acceleration of new innovations [1-2]. The development of elegant organizations and developed process will make use of these technologies. The intention of this collaboration is to raise product quality while optimizing production procedures to reduce costs and enhance output [3]. 3D printing, also known as additive manufacturing, is a technology that enables the formation of three-dimensional objects by building them layer by layer using a digital design even though the fourth industrial revolution has allowed its maximum promise to be achieved. The fourth industrial revolution's important technology is AM, which enables the rapid, precise, and customized conception of complicated products [4-5]. AM is extensively used in rapid prototyping, enabling designers and engineers to quickly manufacture and test product designs. AM has also enabled the development of new design and product optimization strategies that were not previously possible. AM is progressively more being used to produce customized tooling for manufacturing processes [6]. Conventional tooling is expensive and protracted to produce, but with AM, tooling can be produced rapidly and at a lower cost. This allows manufacturers to be more agile and flexible in their production processes [7]. 3D printing offers manufacturers with the opportunity to test the functionality of a design, without having to wait weeks for it to be produced using conventional methods. In the past, long lead times have largely held manufacturers back from investing in innovation. With 3D printing that is no longer the case. Most printers are capable of printing parts within just hours or days, rather than weeks or months. This allows manufacturers to efficiently test new products and make changes where they are needed prior to committing to one design, enabling greater flexibility and innovation in production [8-10]. It supports automation, interoperability, actionable insights and information transparency. There are different components imperative to realize industry requirements. In this upcoming industrial rebellion, AM is a vital technology which has become the main component of product modernism and development. This disruptive technology can fulfill diverse challenges in the future manufacturing system and help the industry to produce inventive products[11-12].

2. Role in automotive industry

Several automakers have been working to develop advanced technologies for automobiles that will allow for improved fuel economy. One such development is the emergence of Additive Manufacturing (AM) or 3D printing, which presents a series of benefits for the manufacture of a single automobile component or an entire vehicle while ensuring strong, suitable physical properties.

Additive manufacturing is a disruptive and rapidly-growing technology that allows designers to prepare quick or rapid prototypes as well as complex designs, which otherwise would not have been possible through legacy subtractive manufacturing processes. The novel technology provides the automotive industry with innovative designs, innovation freedom, and proficiency in the supply chain. This technology is also used for testing, manufacturing, and assembling automotive parts and components with higher efficiency, optimization, and cost-efficiency [13-14].

Additive manufacturing technology is not new to the automotive industry, considering the past couple of years with immense activities in this field. BMW claims that the company had recognized the technology 28 years ago. The automaker has an Additive Manufacturing Center in Munich, where over 100,000 precision components are developed and manufactured each year. These components range from prototypes to small plastic mountings and highly-complex metal chassis parts [15-16].

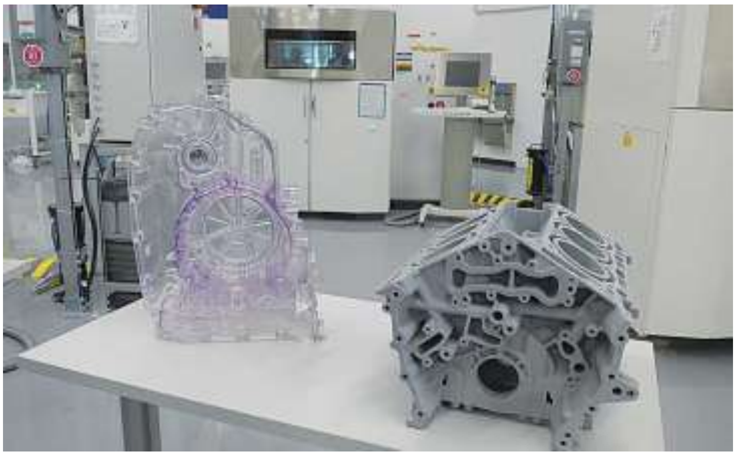

Fig.1 Models for automotive parts [17]

On a similar note, the tool making unit of Volkswagen (VW) established an additive manufacturing center in 2018. VW is looking at the potential of binder jet 3D printing for prototypes and tool production, with a target of introducing additive manufacturing over the next few years for end-use production of parts [18-19]. VW is also looking at a production output of over 100,000 3D printed parts per year. The company has already demonstrated savings in the cost of tooling through its "Automotive Application of the Year" award in 2018. VW has also applied 3D printing to the light-weighting of components in production vehicles, including water connectors for the inside of the Audi W12 engine. When talking about additive manufacturing, there is no "one size fits all" scenario. There are different additive manufacturing technologies that are developed according to specific components / areas / production requirements of the automotive industry. In this respect, it can also be seen that, based on the component that needs to be printed, there are suitable additive manufacturing technologies and processes present. Despite the advantages of additive manufacturing and the level of activity of major automakers, this technology has still not been adopted at a large-scale. Major players in the automotive industry are interested in this technology and have produced components/parts, such as Porsche manufacturing spare parts for rare and classic cars, Mercedes-Benz Trucks and VW manufacturing components for specific vehicles, and the manufacture of a complete car, i.e., the Divergent Blade by Divergent Manufacturing System. However, this is still too little as compared to the vast potential present in the automotive industry [20-21].

One of the main reasons for the low adoption rate is the high initial cost associated with additive manufacturing technology. Further, the cost of materials used for 3D printing is also very high (approximately 70% of the components cost tends to be the material cost). Although there have been immense technological developments and improvements in all additive manufacturing techniques, scaling the manufacturing system and increasing the production rate have not been successfully demonstrated or implemented for the production of very large-scale physical components and parts for the automotive industry [22-23].

Another reason is the material composition of the modern automobile. Traditional automotive manufacturing processes used a wide range of raw materials; some of the additive manufacturing processes may not support materials that are currently being used for manufacturing. Presently, 3D printers can support only up to a few materials at a time for a build. Most additive manufacturing techniques cannot support different materials for printing one single component. Another key area of concern is that additive manufacturing requires technical expertise from the stage of designing the product to the stage wherein the end component is removed for post-curing. Lack of skilled labor is a challenge hindering the adoption of this technology, especially among tier manufacturers across the globe [24-26].

Benefits associated with additive manufacturing, specifically for the automotive industry, are quite evident. Complex components can be manufactured with no wastage of material and quick turnaround time. However, the only challenge encountered is the lack of ability of this technology to produce automobile parts in mass numbers. Mass production of automobile parts has always been the topmost priority, and thus, additive manufacturing will have to wait for a couple of years before the technology is fully adopted by players in the automotive industry [27]. The additive manufacturing technology will be instrumental in developing new designs that previously did not cross the drawing board, owing to several manufacturing challenges. Research and development wings of automakers will experiment with this technology to develop new designs and materials [28].

3. Role in electronics industry

This article is aimed at providing insights into 3D printing of mechanical components for electronics and explaining how additive manufacturing enables faster design and production processes. Just like in any other field, additive manufacturing (AM) offers unique opportunities in electronics too. Its ability to combine multiple materials in single print jobs is very helpful in this industry. 3D printing technologies are much more accessible and simpler than they previously were. This enables significantly faster prototyping, which could reduce lead times, costs and mistakes that disrupt the production process.

3D printing allows the on-demand production of an electronic part with fixed lead time and a confined cost structure, which significantly reduces the time to design and launch a product. It also allows new and old devices to be easily produced with multiple 3D printing materials and low volume directly from a manufacturer's digital inventory or a customer's CAD model. This is the main advantage and will transform the supply chain for electronics and allow manufacturers to instantly cater to the customer demand. For example, using 3D printing for solar panels helps designers to break conventional design rules. This is not only means the external structure but also the internal circuitry which might help improve the performance of components, minimize size, optimize weight and achieve complex and precise geometries [29-30].

The speed and ease of operation associated with additive manufacturing make it ideal for creating quick prototypes. Printing parts with Multi jet fusion (MJF) is a relatively budget-friendly option often chosen for prototyping. Fused deposition modeling, the most accessible form of additive manufacturing, is another viable alternative. FDM is the cheapest and best technology for prototyping due to its simplicity in usage and the cheaper build material. Since the whole process is a lot cheaper compared to the conventional processes, there is a better chance for redesigning, analysis within a short time span [31-34]. Electronic products like PCBs mainly depend on two types of materials: an insulating dielectric substrate and conductive elements. Newer polymer materials with low dielectric constant and semiconducting polymer materials, both with adjustable electronic properties, are being adapted for use in recent times. These advanced materials coupled with 3D printing can open new doors in terms of design and modern developments [35].

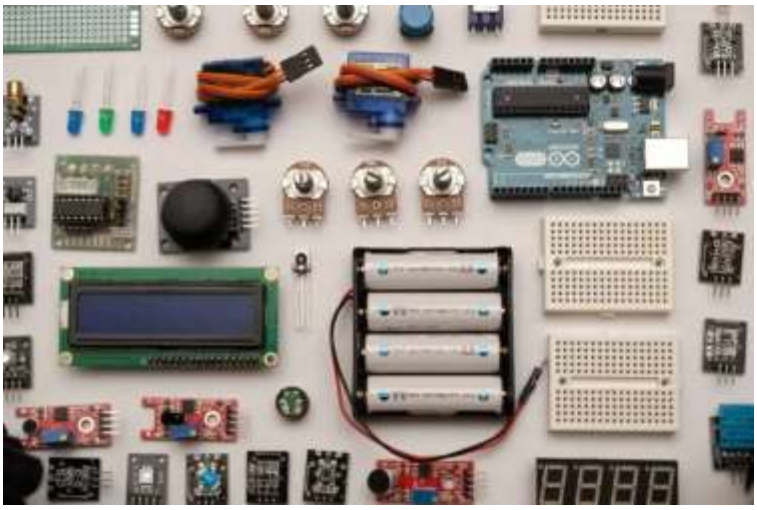

Fig.2 Electronics components[23]

In a traditional process, the circuit is added to the complete part in the later stage but in the additive process, the built circuit is printed along with the part which makes the circuit encapsulate within it which safeguards the circuit from any external damage. For example, the small antenna in a mobile phone can be printed directly into a phone. Electronics like PCBs can be simply 3D printed on non-flat surfaces, whereas conventional methods don't allow this process [36]. In the same way, electronics can be easily embedded into sensors on flexible surfaces, sugar testing strips, prosthetics and customizable batteries. Customized devices and 3D printed batteries can outperform the normal ones as their shapes and sizes are customized to fit a particular product and function thus optimizing the performance. One of the significant features of 3D printing is its production of lesser waste than the conventional subtractive processes and it holds the same even for electronics. 3D printing eliminates the need for extra wiring and additional circuits. Furthermore, the printed electronics eliminates the steps involved while conventional production into a single step thus also facilitating a simpler assembly[37].

4. Role in aerospace industry

In aerospace engineering, technological innovation is the key to soaring new heights. One such innovation that has revolutionized traditional manufacturing processes within this industry is additive manufacturing, commonly known as 3D printing. This transformative technology has catalyzed a paradigm shift in aerospace, offering unprecedented advantages encompassing design, performance, and materials.

Let's examine the pivotal role of additive manufacturing processes, materials, and designs in crafting lightweight structures that redefine the boundaries of what is possible in aerospace engineering. Additive manufacturing (AM), often called 3D printing, has ushered in a new era of possibilities within the aerospace industry, offering many advantages that have reshaped how aircraft and spacecraft are designed and produced. Furthermore, AM enhances supply chain efficiency. The capacity for on-demand production and localized manufacturing reduces the need for extensive warehousing and long lead times, enabling aerospace companies to respond more swiftly to market demands and changes in design specifications [38].

Additive manufacturing has been integrated across a broad spectrum of aerospace applications. Among its most pivotal roles is producing engine components, where performance and weight savings are paramount. 3D printing has redefined the production of critical parts like fuel nozzles and turbine blades. By utilizing complex geometries and high-strength materials, additive manufacturing has led to significant advancements in engine efficiency. The technology enables the creation of intricate internal cooling channels within components, enhancing heat dissipation and overall performance [39].

Additionally, 3D-printed engine parts are often lighter than their traditionally manufactured counterparts, contributing to reduced fuel consumption and emissions — a vital consideration in the quest for more sustainable aviation. In this way, additive manufacturing has become the driving force behind developing cutting-edge propulsion systems, propelling the aerospace industry toward greater efficiency and environmental responsibility. Beyond engine components, additive manufacturing plays a multifaceted role in aerospace. It offers unparalleled versatility in producing structural parts, tooling, and prototypes. Structural components, such as aircraft brackets and interior fittings, benefit from the ability to design and print complex shapes that optimize strength-to-weight ratios [40-41].

Tooling, which is essential for manufacturing and repair processes, can be rapidly and cost-effectively produced through 3D printing. This can include fixtures that hold components during traditional manufacturing methods or tooling to assemble or disassemble parts of a commercial jet engine [42].

Furthermore, in repair and maintenance, 3D printing has proven invaluable. It enables the efficient creation of replacement parts on-site, reducing downtime and costs associated with sourcing hard-to-find components. This versatility across diverse aerospace applications showcases the transformative potential of additive manufacturing, making it an indispensable tool in the arsenal of aerospace manufacturers and maintenance teams. At the same time, polymer composites have carved out their own niche within additive manufacturing systems. These materials, which combine the strength of fibers like carbon or glass with the versatility of polymers, offer an exceptional combination of lightweight characteristics and structural integrity.

In aerospace, where every ounce matters, polymer composites have been instrumental in reducing the overall weight of aircraft and spacecraft, leading to enhanced fuel efficiency and payload capacities. Moreover, the ability to tailor the composition of these composites allows engineers to fine-tune material properties to meet the specific requirements of a given application [43].

Fig.3 Aerospace components [38]

One of the paramount concerns is the certification and qualification of 3D-printed components. Ensuring the reliability and safety of these parts is non-negotiable in aviation and aerospace, where lives are at stake. Establishing rigorous standards and procedures for certifying additive manufacturing processes and materials is imperative. Additive manufacturing is poised to reshape the aerospace industry profoundly, ushering in an era of innovation, efficiency, and unprecedented possibilities. However, the road ahead is not without its hurdles. Certification and qualification processes, stringent quality control measures, scalability challenges, and industry-wide collaboration are paramount to ensuring the safe and reliable integration of 3D printing into the manufacturing landscape of the aerospace industry. The aerospace industry must continue to invest in research, development, and cooperation to overcome these challenges. Doing so can unlock the full potential of additive manufacturing, where complex, lightweight, and highly customized components become the norm, paving the way for a future where aerospace systems are not just advanced but also safer and more sustainable [44].

5. Role in medical industry

Currently implants are the most extensively produced 3D printed parts in the medical industry. They offer a whole range of advantages, particularly when it comes to the replacement of bone material. These parts are printed using CAD files, often generated using medical imaging techniques.

Since implants are usually custom-made products for a well-defined purpose, additive manufacturing is ideal, due to its ability to produce unique items quickly and cost effectively. Until recently these types of implants would usually have been mass-produced and then adapted for the patient, often by the surgeon. It can make simple parts such as femur implants or hip bones tailored to the individual patient, figure joints, zygomatic bones and jawbones, as well as complex implants such as orbital implants, cranial bones and thoracic implants. And implanting/attachment of artificial teeth is now a standard application for 3D printing [45].

Due to 3D printing's comparatively fast manufacturing times and the possibility of on-demand production (i.e. implants as and when they are needed), the medical sector is increasingly recognizing the benefits of this technology and is using it for both standard implants, such as individual vertebrae in the spine as well as more customized options. Surgical aids often need specifically designing for the individual patient and the respective operation e.g. templates help with drilling the cranial bone to millimeter precision. Due to the high-level of accuracy using processes such as DMLS (individual features of less than one millimeter can be achieved - depending on material biocompatibility and intended application), there are huge benefits to using 3D printing for this. Accurate CT scans of a drill section can create precise files that allow the production of parts quickly. The resulting needs-based drilling templates allow for more accurate work and help avoid dangerous errors during the operation [46-47].

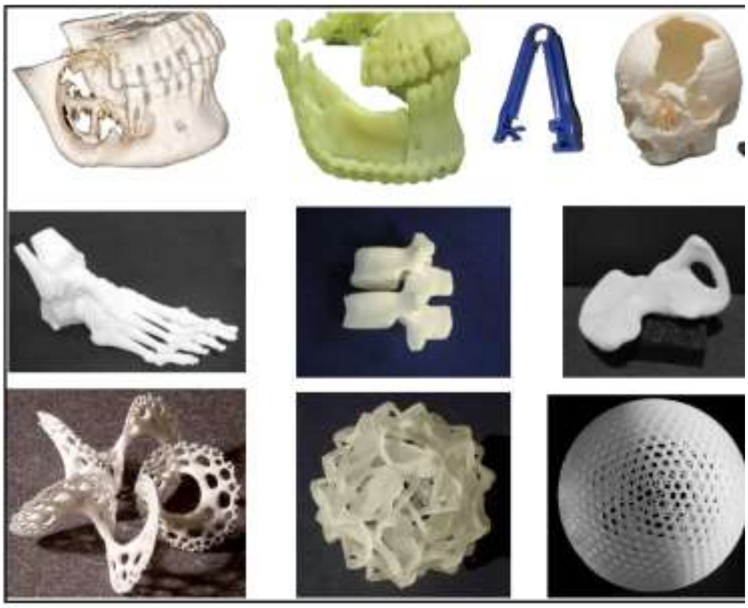

Fig.4 Medical applications [44]

Another additive manufacturing material used in the production of medical devices and custom-made products is the relatively new Micro Fine Green. Using this bright green material to create microscopic structures, opens a whole range of possible applications which were previously not feasible in medical 3D printing. Single parts for pacemakers, only a fraction of a millimeter in size, are just as conceivable as miniaturized catheters or liquid and gas injectors [48].

By using processes such as DMLS and stereo lithography to print complex geometries, there are almost no limits to what additive manufacturing can produce for the medical industry. Besides providing templates for specific operations, which differ from patient to patient, the new manufacturing methods also allow innovations in medical instruments for the operating theatre. 3D printing makes it easier to produce instruments that were previously not economically viable or, in some cases, even impossible [49].

For example, DMLS can produce surgical devices that allow special drilling or incisions, which can crop up repeatedly in medicine. Additive manufacturing applications also include other specialized medical instruments to better suture surgical wounds or used as tools during the surgery itself. Instruments precisely adapted to an individual surgeon, such as handles for scalpels, are an example. Parts manufactured from special plastics using additive production can also be used, for example as highly specialized brackets or spacers. Such extensive use of 3D printed parts in the medical industry is possible because the materials and methods combine a whole range of benefits including; mechanical strength, cleanliness and ease of cleaning and sterilisability. It is also cheaper to produce parts designed for a single task or purpose than by traditional production methods [50].

For a long time, 3D printing has been a useful manufacturing process for specially adapted prostheses and orthoses. Compared with other manufacturing processes, 3D printing allows you to produce individual parts that are specially tailored to an individual patient, inexpensively, quickly and easily. Parts have to be specially adapted in the production of both orthoses and prostheses. However, whilst in prosthetics missing limbs or body parts are replaced, in orthoses the goal is usually more the support or immobilisation of individual limbs or joints. In both cases, additive manufacturing helps enormously in bringing innovative ideas to market faster and more cost-effectively. This way, people who urgently need the assistance of these medical aids can get assistance more quickly. An example of this is the faster product development of exoskeletons - i.e. orthoses that allow users a better functioning musculoskeletal system. Manufacturing processes such as injection moulding often take a long time, while the waiting period for 3D printed parts is far less. 3D printing has similar advantages in the production of innovative prostheses, which need to be specially adapted to the respective wearer, or in prototypes of entire new generations of prostheses which, like exoskeletons, have yet to go through a product development cycle [51-53].

6. Conclusion

Additive Manufacturing and 3D printing technologies have revolutionized engineering processes, especially in complex and specialized industries such as aerospace and automotive. Evolving from a technology merely used for prototyping to a technology utilized in every aspect of the industry, AM can be employed to fabricate parts, components, tools and for repair and restoration. AM has the advantage of creating lightweight parts with flexible design and minimum waste. Moreover, the parts are quickly printed on demand which allows for a cost effective and environmentally friendly manufacturing process. AM also positively affects the affordable and clean energy and contribute to the decent work and economic growth. It is evident that 3D printing, and additive manufacturing are quickly becoming the favorites manufacturing techniques, especially for industries with forward thinking decision makers. Weighing the advantages of AM technologies prove that they will be the manufacturing pillars in upcoming industrial revolutions. The presented article was used to explain the various role and applications of AM in aerospace, automotive, medical and electronics industries.

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