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An Overview of Recent Trends in Additive Manufacturing with Polymer Powders, Production, Applications and Developments

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In this article, an overview of three dimensional printing, also known as additive manufacturing (AM), with a focus on polymers is presented. As a starting point the additive manufacturing concept is described. Several well established technologies, including their advantages and drawbacks and a list of polymers, which are commonly used in commercial printers are evaluated and outlined. The additive manufacturing applications together with the key developments are also presented. The article further highlights major industrial applications, directions for promising research are identified, possible full exploitation potential of additive manufacturing in industries and finally outlines future challenges in this rapidly growing industries.

Keywords: Additive manufacturing, Additive manufacturing technologies, Applications, Developments, Challenges.

INTRODUCTION

Compared with subtractive manufacturing technology, additive manufacturing is an operation of combining materials to manufacture products with 3D model data usually layer by layer [1] and it is commonly also referred to as 3D printing [2,3]. 3D printing, also known as "additive manufacturing" (AM), is an emerging technology attracting interests from industries and academic communities [2-4]. The technology produces three-dimensional parts layer by layer from a material, be it metal based or polymer [2,3] and relies on a digital data file being transmitted to a machine which then subsequently builds the component. A wide range of materials which are different can be used for 3D printing and these include materials such as acrylonitrile butadiene styrene (ABS) plastic, pply(lactic acid) (PLA), polyamide (nylon), stereo-lithography materials (epoxy resins), silver, polycarbonates, titanium, steel, wax, photopolymers and polyamide [4]. The majority of biomaterials used in medical 3D printing technology currently, such as composites, ceramics, hard polymers and metals, are stiff and thus used for orthodontic applications widely [5]. Hydrogels, which are soft polymers are widely used in bioprinting cells for organ/tissue/fabrication [6]. With increased and more viable research, 3D printing has been extended to more fields. For example, in construction industry, there were a group of houses in China being successfully mass printed in less than a day [7].

Polymers are by far the most common materials for 3D printing technology [8] and their applications are diverse in different fields. There are usually two types of polymers depending on their origins. The first type includes natural polymers such as cellulose, natural rubber, *etc*. [9] whereas the second type of are synthetic and petroleum based polymer products such as polyethylene, polypropylene, *etc*. [10]. The most common types of synthetic organic polymers, which are commonly found in households are: Low-density polyethylene (LDPE) [11], high-density polyethylene (HDPE) [12], polypropylene (PP) [13], polyvinyl chloride (PVC) [14], polystyrene (PS) [15], nylon [16], nylon 6, nylon 6,6, Teflon (polytetrafluoroethylene) [17], thermoplastic polyurethanes (TPU) [18]. The list of 3D-printable polymer materials is even longer than the one for metals, but some of the most popular are acetal [19], acrylic [20], acrylonitrile [21], acrylonitrile butadiene styrene (ABS) [22], acrylonitrile styrene acrylate (ASA) [23], high impact polystyrene (HIPS) [24], nylon, polycarbonate (PC) [25] and polyether ether ketone (PEEK) [26].

The improvement for 3D part printing process and advancement of material processing attracts market to prefer this technology that helps to lead the transition of old production system towards additive manufacturing system to be used as user interfaced parts production method are among 21st century technology to fulfill basic human engineering needs which is under alarming growth [27]. This review article gives a direct overview of how the additive manufacturing (AM) technology has developed and where it currently stands today. In addition, this article takes a closer review at how additive manufacturing is evolving continuously the design process and how the role of the designer has been changed by this new world class technology. The adoption of additive manufacturing and other advanced manufacturing technologies is demonstrating the future manufacturing process in which value chains are smaller, shorter, localized more customized, more collaborative and provide more sustainability advantages [28,29].

Additive manufacturing technologies: Additive manufacturing technology is largely used to manufacture functional prototypes and parts for fits and assembly. In terms of the printing materials, polymer-based materials account for the largest share, particularly in the production of medical implants [30,31]. In addition, a number of process specific characteristics, machine associated constraints, materials and possible qualities both as dimensional and geometric deviations and surface qualities influence the opportunities that this technology can provide [32]. A number of additive manufacturing processes currently available commercially each have their own advantages and disadvantages [33]. The additive manufacturing technologies can be categorized into the following seven process classes and markets where they are utilized (Table-1) [34-36].

Additive manufacturing can be categorized in various ways according to the functional framework of the material. Although the methods of classification can also include the patterning energy, the technique of generating primitive geometry, the nature of used materials and the support procedure [37-39].

Vat photopolymerization: This is an additive manufacturing process in which the photosensitive polymer of the liquid in the barrel is selectively cured by using a photo-activated polymerization reaction [40]. In vat polymerization, liquid photosensitive polymer resin is used to build model layer by layer [41]. After curing each new layer, as the platform moves the object to be manufactured downward, ultraviolet light is needed to harden or cure the resin as shown in Fig. 1.

Unlike the powder method, during the construction phase, the material has no structural support because the process uses liquid to form the object, where the unbound material provides the support. Support structures often need to be added in this

TABLE-1
ADDITIVE MANUFACTURING PROCESS TYPES AND ATTRIBUTES, INCLUDING MATERIALS UTILIZED IN MACHINES AND TYPICAL MARKETS AND KEY DEVELOPMENTS

Process	Materials	Markets	Key developments
Vat photopolymerization	Photopolymers	Prototyping	(DLP/LCD/LED) technology is projector-based and cures entire layers at once. Stereolithography patents are expiring thereby opening up the marketplace
Material Jetting	Polymers, Waxes	Prototyping, casting patterns	3D printing is now being investigated by traditional companies. Significant interest in printed electronics.
Binder Jetting	Polymers, Metals, Foundry Sand	Prototyping, Direct part, Casting molds	Colourjet that is based on Zcorp is being marketed by 3D systems. Sand printing has increased as a result of ExOne which builds metal parts. Marketplace is now dynamic because of Voxeljet.
Material extrusion	Polymers	Prototyping	Proliferation of 3D printers as a result of expiration of patents. There is renewed interest in manufacturing parts *via* extrusion.
Directed energy deposition	Metals	Prototyping, repair, Direct part	Part production is led by electron beam with wire. Laser deposition heads marketed as add ons to existing machine tools by manufacturers.
Powder bed fusion	Metals Polymers	Direct part prototyping	The most-used platform for functional parts. Starting to see new polymer machine manufacturers
Sheet lamination	Metals Paper	Direct part	Significant R&D investments have been significant Increase in metal machine manufacturers.

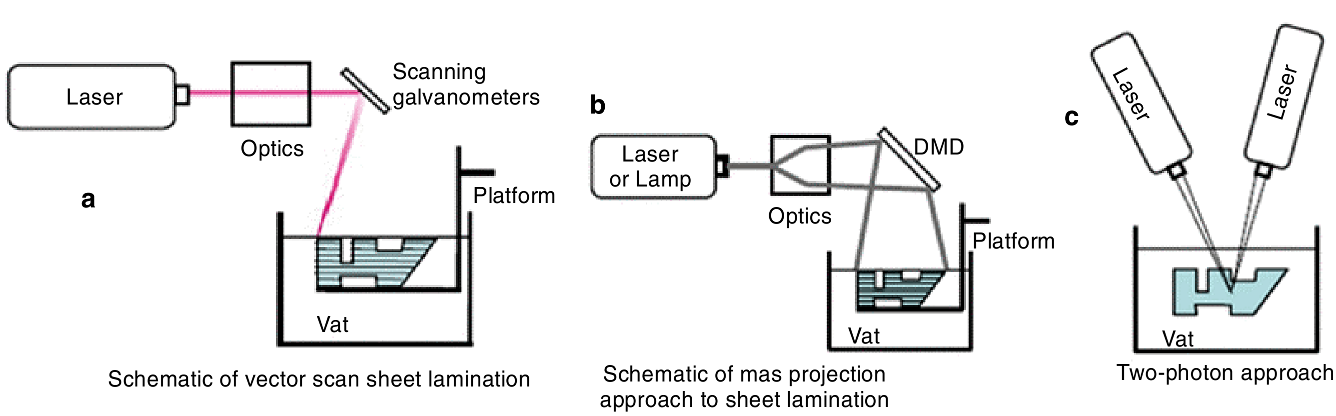

Fig. 1. Schematic diagrams of three approaches to photopolymerization processes

case. A process using UV light or photo polymerization cures the resins, whereby the motor controlled mirrors direct the light across the surface of the resin. The resin cures or hardens when it comes in contact with the light.

There are few factors which have benefits in vat photo-polymerization are (i) provides a good finish and high level of accuracy; (ii) process is relatively quick; and (iii) contains max model weights of 200 kg and large build areas. However, have simultaneous also disadvantages of vat photo-polymerization like (i) expensive technology; (ii) post processing time and removal from resins is lengthy; (iii) photo-resins produced have limited material use; and (iv) for parts to be strong they require post curing and support structures.

Material jetting: This is an additive manufacturing operation in which build material made of droplets are deposited selectively on a support material [42]. Two-dimensional inkjet printers create objects in a similar way to "material ejection." The continuous also called drop on demand (DOD) method sprays material against the build platform, solidify on the platform and then build the model layer by layer (Fig. 2). Nozzles that move horizontally on the build platform deposit material. The complexity of controlling material deposition varies from machine to machine. Ultraviolet can cure or harden material layers and because the material has to be deposited in tiny droplet form, thus type of material is a limit to what can be used. Due to their viscosity and ability to form droplets, commonly used materials are polymers and waxes.

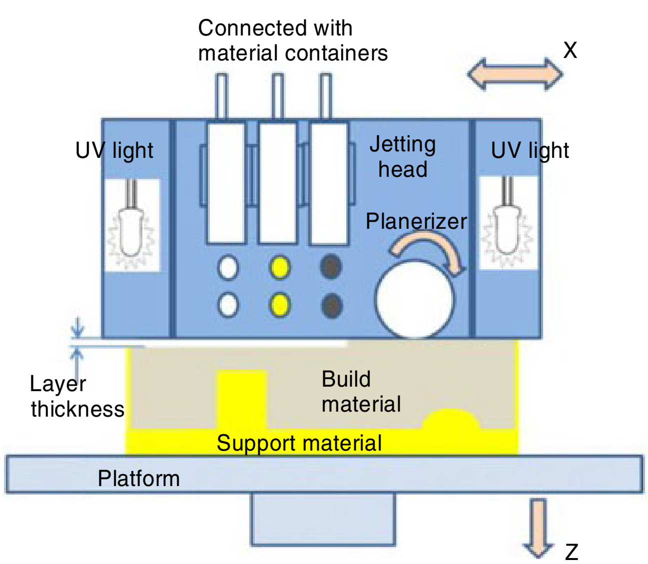

Fig. 2. ProJet 5500X multi-material jetting system print head working principle

This method has two advantages *viz.* (i) low waste from this process as there is a high accuracy of droplets deposition; and (ii) a single process can provide multiple material parts with different colours. However, have disadvantages like (i) main requirement is availability of support material; and (ii) only polymers and waxes can be used and high precision can be achieved.

Binder jetting: This is an additive manufacturing operation where selective deposition of liquid bonding agent takes place inorder to mix powder materials [43]. Dual materials are used in the binder injection process powder based materials together with binders. The binder, which is usually in liquid form acts as a binder between the layers of powder and the powder from the building material. The print head moves diagonally on the *x*- and *y*-axes of the machine and layers are alternately deposited for construction along with binding materials. After each layer, the object to be printed is place on the build platform (Fig. 3). The material properties are not suitable for structural parts as a result of the bonding method employed.

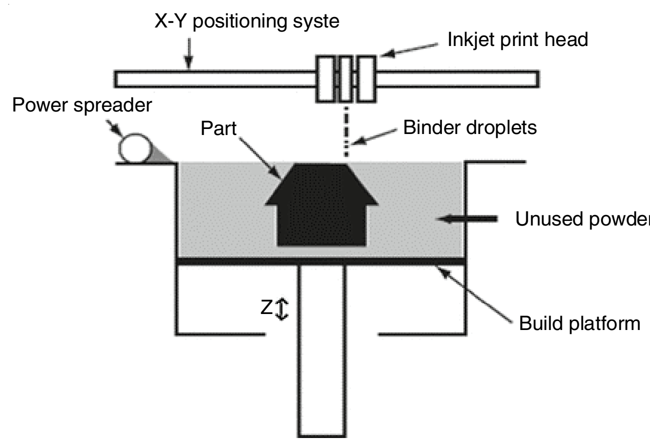

Fig. 3. Schematic of the binder jetting process

Although the printing velocity is relatively high, supplementary post processing may increase the overall processing time. As with other powder based manufacturing protocols, the print product can be self supporting in the powder bed and expunged from unbound powder after completion. This automation is commonly attributed to 3DP technology.

The binder jetting has advantages like (i) parts can be made in various colours; (ii) can use multiple materials: metals, polymers and ceramics; (iii) usually faster than other processes; and (iv) two material methods can achieve a huge number of various binder powder combinations with different mechanical properties. However, have some issues in this technology like (i) due to the use of adhesive materials, it is not always suitable for structural parts; (ii) additional post-processing may increase the time of the entire process; (iii) a successful realization of this process not only involves the printing process itself, but also a suitable post-processing procedure, both of them have a huge influence on determining the mechanical performances of the part manufactured [44] and this technology is mostly used to make conceptual models [45,46]

Material extrusion: This is an operation of additive manufacturing where there is selective dispensing of material through a nozzle or orifice [47] and based on the principle of layered manufacturing technology [48]. The company Stratasys has trademarked fuse deposition modelling (FDM) a common material extrusion process [49]. After drawing through the nozzle and heating, the material is deposited layer by layer. After each new layer is deposited, the nozzle will move horizontally while the platform vertically moves up and down. This technology is very popular and has been used in several inexpensive

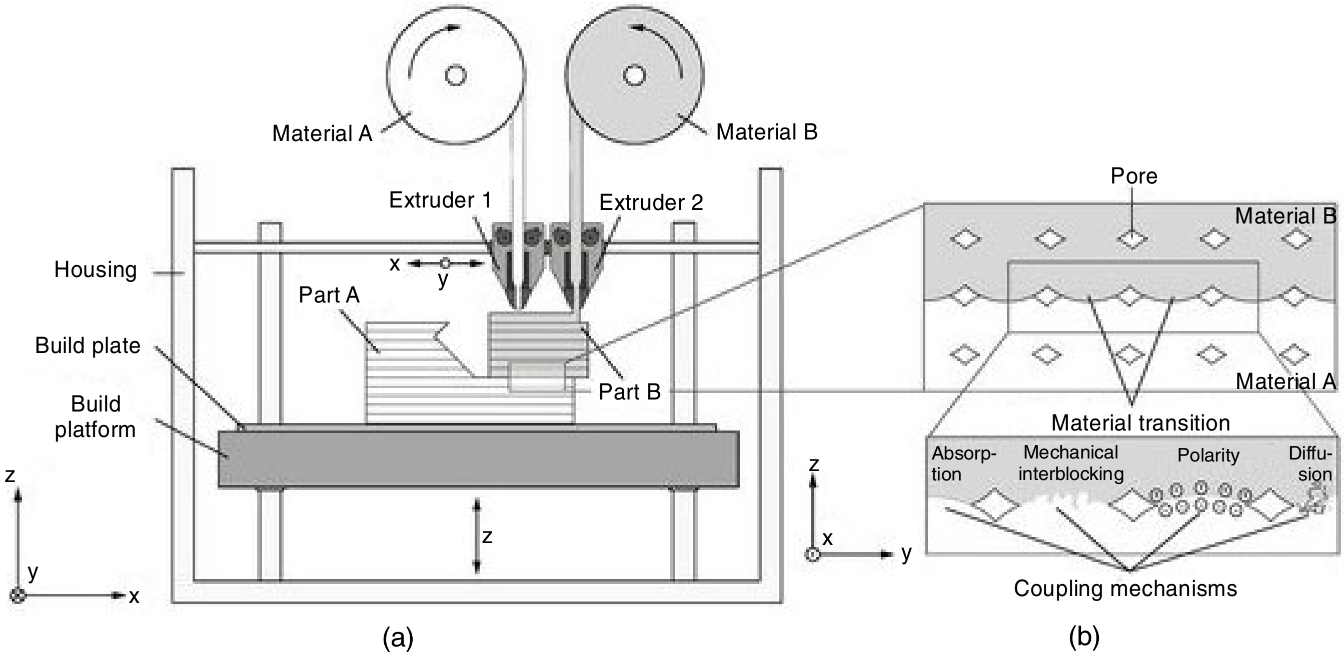

Fig. 4. Schematic representation of material extrusion (ME) principle and (b) material transition including relevant coupling mechanisms

amateur and home 3D printers. When the factors that affect the quality of the final model are successfully controlled, the process has great potential and feasibility. FDM's layer-by-layer construction is identical to other 3D printing operations, but changes in that the material is added in a continuous flow through a nozzle under constant pressure. The pressure must be kept constant and stable to achieve accurate results. The material layer is bonded using chemical reagents alternatively by controlling the temperature and then the material is fed into the machine as a spool, as shown in Fig. 4.

This technology is (i) inexpensive and widespread process; and (ii) ABS plastic is easily accessible and has good structural properties. However, some of the disadvantages are limited *e.g.* (i) final quality limited and reduced by the nozzle radius; (ii) when compared to other processes, accuracy and speed are low and material nozzle thickness limits the final model; and (iii) to increase quality of finish constant pressure on material is required.

Direct energy deposition (DED): This is an operation of additive manufacturing where materials become fused by melting using focused thermal energy as they are deposited on a substrate [50]. Directed energy deposition (DED) covers a series of terms such as laser engineering mesh forming, directed light manufacturing, 3D laser cladding and direct metal deposition. This complicated printing operation is used to add other materials or repair existing components. The nozzle of the DED machine is fixed on a multi axis arm and deposits the molten material onto designated surfaces (Fig. 5). The operation is identical to material extrusion and the nozzle moves in many directions and does not point specifically to an axis. Materials which are deposited from any angle through 4 axis and 5 axis machines where they melt with the use of electron beams and lasers during deposition. This method can be used for ceramics and polymers, but is usually used for metal in the form of wire or powder. Repair and maintenance of structural parts are typical applications.

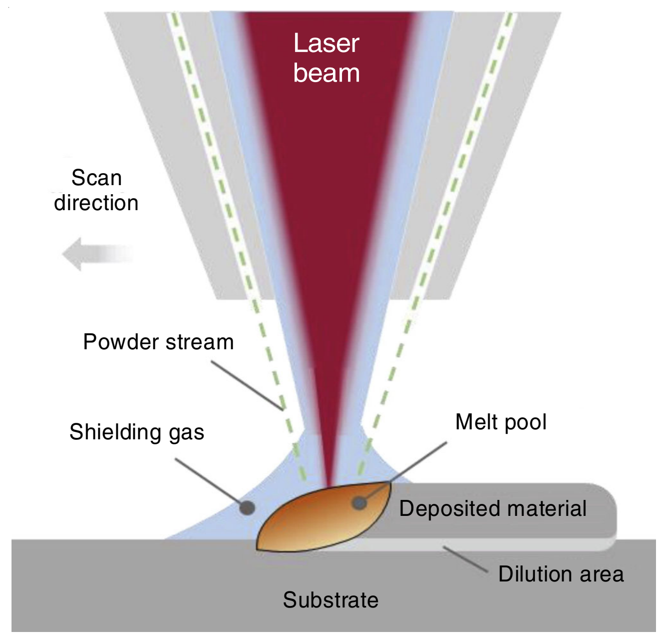

Fig. 5. Schematic representation of direct energy deposition (DED) process

This method has advantage over other technology as (i) the operation produces repair work with quality, which is very high because of the ability to control to a high degree the grain structure; and (ii) there is a need to maintain a balance between speed and surface quality, but speed is often sacrificed to obtain high accuracy and predetermined microstructures for maintenance applications. However, few drawbacks for this technology are (i) processing of post finishes varies depending on plastic or paper material used to achieve the desired effect; (ii) use of the material is limited; and (iii) to get the process into a more mainstream position, more research has to be done on the fusion process.

Powder bed fusion: This is an operation of additive manufacturing in which regions of a powder bed are fused selectively by thermal energy. Selective heat sintering (SHS), direct metal laser sintering (DMLS), electron beam melting (EBM), selective laser melting (SLM) and selective laser sintering (SLS) are the most commonly used powder bed fusion printing processes [51]. At present, the SLS research mainly focuses on process optimization, material development and application extension [52-55].

The powder bed fusion (PBF) process utilizes an electron beam or laser to melt powdered materials. PBF process involves spreading the powder material on the preceding layer, which involves mechanisms which are distinctive realized by using rollers or blades. A hopper or hopper under the bed or next to the bed provides a fresh supply of material (Fig. 6). Electron beam melting (EBM) requires vacuum and can be used with metals and alloys to manufacture parts. Direct metal laser sintering (DMLS) is similar to SLS, but instead uses metal by sintering powder film by film. Selective thermal sintering (SHS) is different from other processes because it uses a heating thermal print head to fuse in sync powder materials and uses the rollers to add layers betwixt layer fusions and the platform will lower the model.

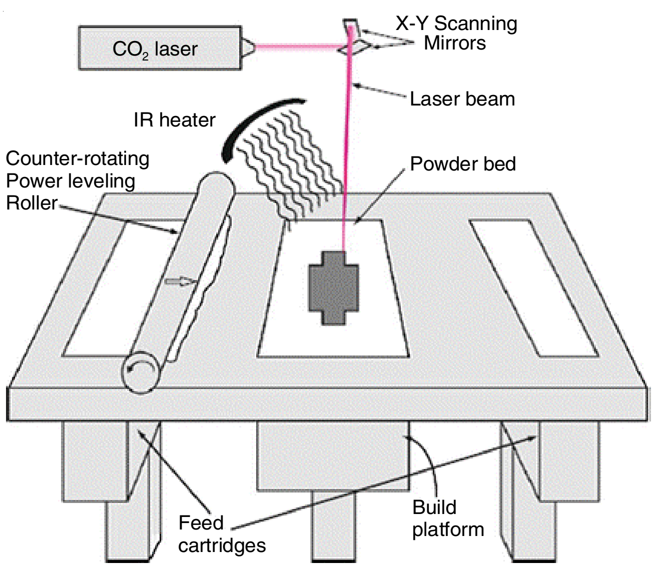

Fig. 6. Schematic of the selective laser sintering process

Few advantages of the technology are (i) inexpensive relatively; (ii) suitable for prototypes and visual models; (iii) technology can be integrated into small scale office sized machine; (iv) support structure is determined by the powder; and (v) material options have a wide range. But this technology has also few disadvantages which are (i) slow relative speed; (ii) materials lack structural properties; (iii) size limitations in size; (iv) high power usage very high thus expensive; and (v) powder grain size determines finish outcome.

Sheet lamination: The sheet lamination operation includes laminated object manufacturing (LOM) and ultrasonic additive manufacturing (UAM) [56]. Ultrasonic additive manufacturing uses metal tapes that bond metals or sheets together by ultrasonic welding. Additional machining and removal of unbonded metal are required during the welding process. A laminated manufacturing plant (LOM) utilize a layer by layer method, which employs an adhesive in the form of paper and material instead of welding (Fig. 7). By using the cross hatching method in the printing process, you can easily complete the removal operation after construction. Laminated products are often used for visual and aesthetic models but are unsuitable to be used as structures. Ultrasonic additive manufacturing (UAM) uses metals such as copper, stainless steel, aluminum and titanium. This process uses low temperatures and can create internal geometry. Since metals do not melt and require little energy, different materials can be bonded together.

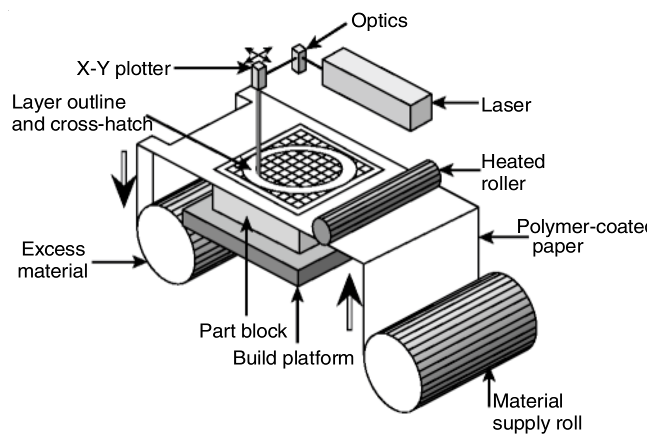

Fig. 7. Schematic of the LOM process [Ref. 57]

Likewise other methods, this method has also few advantanges like (i) this process has high speed and ease of material handling and low cost; (ii) cutting of material is very fast as it is determined by the outline of the shape and not the cross sectional area. Few disadvantages are (i) processing of post finishes varies depending on plastic or paper material used to achieve the desired effect; (ii) use of material is limited; and (iii) in order to get the process into a more mainstream position, more research has to be done on the fusion process.

Advantages of additive manufacturing

1. In additive manufacturing it is much cheaper and faster to print very complex parts unlike simple part of the same size.

2. New products can be printed by simply making changes to the CAD file if a part needs to be changed.

3. Parts that move do not require assembly such as bicycle chains and hinges as these are printed directly onto the product from the metal and thus significantly reducing the part numbers.

4. Immediately after finishing the stereo lithography (STL) file, a prototype can be created with a 3D printer. When the part has been printed, its properties can be tested immediately without waiting for months or weeks for a part or prototype to be produced thereby greatly reducing lead time which is very important in production of parts.

5. Even though complicated parts with parameters that are specific and high technical applications can be manufactured by professionals, kids in primary school have been able to create

figures using 3D printing demonstrating that there is little skill that is required for manufacturing.

6. In additive manufacturing anything can be created and designed with the CAD software demonstrating that there are few constraints that are encountered in the process.

7. Very small amount of material is since only what is needed is used thus there is less waste to the environment.

8. Scientists and Engineers can be able to program parts exhibit specific colours in their CAD files and thereby allowing printers to utilize materials of any colour and print leading to a range of shaded materials.

Limitations of additive manufacturing

1. Most of the printers deposit material at a slow rate per hour significantly. Other manufacturing operations may be undou-btedly quicker depending on the part that is needed.

2. Parts produced using traditional methods promote lower production costs unlike in additive manufacturing.

3. Rigorous knowledge of material design and extensive knowledge of the additive manufacturing machine itself is required to make quality parts.

4. The dimensional accuracy and surface finish is sometimes of lower quality as compared other processes of manufacturing and requires post processing.

5. Since parts are printed one at a time, it means this is a discontinuous process which impedes economics of scale.

6. Polymer products in most cases are small in size and even though larger machines which are large are available, they usually come at a higher price.

7. Multiple interfaces and layering can cause defects in the product leading to poor mechanical properties.

Applications of additive manufacturing in various industries

1. Aerospace industry with efficient and more robust parts that are lighter such as nozzles for fuel, metals, flame-retardant polymers and thrust chambers.

2. Lightweight and high-strength structures required in the space industry.

3. Replicas of art, architecture, preservation and restoration encompassing cultural heritage.

4. In the automotive industry such as customized cars, where industry is aiming at less potential for mainstream production as a result of large volumes.

5. Storage devices as applied in photonics and energy harvesting.

6. Architecture including building prototypes; structures that are 3D printed: bridges and buildings.

7. Testing designs by fabrication of parts which is the primary original goal of additive manufacturing and termed as prototyping.

8. Orthodontics such as custom-made crowns, implants, custom made braces.

9. New nanocomposite materials and nano-devices including broad nanotechnology

10. Designing projects, workforce training and this covers the education sector.

11. Different foods can be designed into complex intriguing shapes, such as sweets and confectionary.

12. Custom-made shoes, smart clothing as a part of consumer goods.

13. Designs and new forms and this includes art.

14. New designs of sophisticated jewellery.

15. Medical aspects involving prosthetics, implants, scaffolds, devices, aids for hearing, organs and tissues which are printed, delivery of drugs, surgery models; electric sensing materials.

Impact of additive manufacturing technologies in industry

1. Additive manufacturing opens unlimited possibilities in design for innovation; new complex shapes are allowed, research on and synthesis of materials which are new such as architecture scafoldings, metamaterials and foams is greatly stimulated.

2. The additive manufacturing manufacturing technology is highly versatile as it allows use of, customization and local resources. As a bonus there is great flexibility which is realized with no cost penalties, complexity for higher design and a reduction of assembly work resulting in steps of production which are less.

3. Products can also be printed as in when and where they are on demand with no need for special warehouses, long distance transport or packaging and thus distribution made easier.

4. New organizations and businesses are being formed and funding agencies including governments are investing a lot of support into infrastructure as a means of exploring this industry and also supporting it.

5. Healthcare which is customized together with medicine which becomes personalized including tissue scaffolds, devices for drug delivery, custom implants dentistry bridges, crowns, braces and safety equipment such as helmets.

6. A positive impact on the environment will be realized as additive manufacturing is sustainable by involving less material and less waste. In addition there is a decrease in transportation and this leads to lower carbon emissions.

7. Education of lecturers and teachers who will train and disseminate knowledge to the workforce on additive manufacturing will be needed.

8. New research innovative directions are opened and these include: invention of new materials for architecture, printers with new designs, 3D processes being modelled and improvement in the 3D printing technologies.

9. The ability to 3D-print a wide range of complex shapes with one piece of equipment has been further complemented and strengthened with no need for making new tools. Designs which are new are optimized and have a greater possibility of involving new shapes and microstructures which are tailored parts and have fewer parts.

10. There is tremendous economic growth due to businesses and new companies forming, jobs and new specializations are have been created. Manufacturing shifts from the few countries with low labour costs to local printing, thereby impacting local global and local economies.

11. Protection of patents and intellectual property laws and regulations have to be introduced as failure of 3D-printed parts becomes more complex and liability grows.

12. Fused filaments release particle emissions, which are potential hazards to health.

13. Manufacturing of weapons of mass destruction also poses as a security threat and this has to be controlled.

Global perspective of additive manufacturing: Additive manufacturing comes with a tremendous potential that has been globally recognized and appreciated by a large number of countries that have initiated programs to hope to develop additive manufacturing capabilities. Additive manufacturing has become an essential part of the whole picture of the manufacturing process and industrial applications which are real and can be seen occurring [58]. The first mass-produced products in this respect have been caps and dental crowns [59,60], but major companies in the aerospace industry are devising tangible plans for companies of additive manufacturing worldwide in recent times. In most of the industries in European and Asian countries, metal additive manufacturing is being widely studied as a new manufacturing method and well documented that metal additive manufacturing was a European invention that began in the mid-1990s, so European industry has proposed the first application, which is reasonable, but the US is growing very fast.

Not to be left behind, China started its own aerospace engine development in 2016 which is a highly significant program and we have seen numerous additive manufacturing machines from China being revealed to the market [61]. The development of the additive manufacturing industry has been funded by Singapore for numerous years and competent infrastructures have been established at most of the research institutes and universities [62,63]. Russia identified technology in additive manufacturing as one of the most important areas of research and has already put out intellectual property on this. We are now seeing a movement which is global becoming more solid every month and professional but unfortunately this is not yet being experienced in Africa.

Globally additive manufacturing has immensely been developed but different countries with differing economies are at different levels of capabilities as the countries do not possess the same financial rigour as some of the countries have limited resources to develop their respective capabilities. The US is, not surprisingly however at the forefront of the ever increasing technologies due to its very strong economic prowess and very firm research practice which is in place. Australia and China are at the forefront in two industries, which combine 3D printing, robotics, data analytics and advanced materials in a bid to transform how patient-specific implants are made. The other developed countries such as Spain, Germany and Italy also have extended capabilities in other respective categories, such as 3D printing providers, manufacturers of hardware, developers of software and vendors. The United Arab Emirates particularly known for oil, changed its economy drastically in the last few decades and announced recently plans to become the epicenter of additive manufacturing through massive construction projects.

When used in additive manufacturing for metals, the main issues to consider include production friendly to additive manufacturing and the supply of metal powder is always sufficient. These are very important basic aspects required to demonstrate the continuous development of the technology. Integrating metal additive manufacturing machines into the entire production process also requires the establishment of professional knowledge and consultation when appropriate to achieve a functional working environment. Today, applications used in additive manufacturing metals include industries that require highly complex, bionic structures and lightweight parts. This does apply mainly to the energy, aerospace, medical implant, dental and automotive industries.

Currently, different additive manufacturing metal processes are used in industry and the most promising manufacturing operation is laser powder bed fusion (PDF). It is the most controllable, accurate and predictable process. For larger parts, the material supply per unit time requires adjustments such as wire feed and the test equipment should be designed to verify that approach. For large and individual parts, powder nozzle production systems like LENS or DMD are used, but these suffer from limitations such as low density, high stress potential and serious problems with powder recycling. Unique technologies have been adapted to make additive manufacturing metals more user friendly and viable for manufacturing processes. The metal additive manufacturing process produces a fully dense and inaccurate rough and raw surface part. Surface machining for accuracy and treatment together with heat treatment to avoid stresses have to be designed and adopted in line with selective laser melting (SLM). Recycling, powder handling and support removal also need automation during the process.

Additive manufacturing machines now use many different metal alloys and metals. All weldable metals and their combinations can be processed by the powder melting process and more than thirty metals have been approved for use in the system. Technically speaking, titanium aluminum and various other steels and their alloys have been widely used. High nickel and chromium alloy steels can be used in turbine blade applications such as Inconel. Precious metals such as platinum, silver and gold are specifically used for jewelry applications and many university projects in Europe and America are developing the use of copper. The application of titanium-zirconium mixtures has been successfully developed for medical purposes, as well as alumina and silicon carbide for dental applications. The application of these ceramic mixtures usually has the disadvantage of undergoing high cooling gradients during processing, leading to cracking and requires higher preheating during processing. Glass has identified the first batch of silicon oxide applications and recently obtained a patent. The multi-material feed has been tested on some machines for scientific applications before, but due to limited adjustments, the handling of powders in the process and the large amount of waste materials due to mixing during the process, these machines cannot work properly.

In the next few coming years from now established production of parts will be seen, which are specialized in factories around the world. This new technology will be seen as part and parcel of engineer, student and designer fellowship at colleges and universities globally. “Future Manufacturing Now!” will be a very fast and exciting development in the additive manufacturing industry.

Research and development opportunities in additive manufacturing space: More research and skills development and research capacity is very crucial in this important space of additive manufacturing design and will lead to a huge positive contribution and development of novel uses for the technology. Development of scanning technologies like 3D white light scanning and computer tomography have inspired the fields of bionics and design through emergence of real life organic products. Future development in additive manufacturing design will have to consider alternate creation of data and possible modification.

Trends and the future: Many exciting developments are being experienced by the additive manufacturing industry with new systems, materials and applications are being developed as industry and researchers try unique technologies. Many trends in additive manufacturing have come into focus and among them are advances in metals, the availability of new design tools. Additive manufacturing will lead to technologies that will launch entirely new industries [64,65]. Potential implications of 3D printing technology or additive manufacturing in a wide range of industries is being recognized [66,67]. Additive manufacturing developments present opportunities for potential growth in developed nations where traditional manufacturing sectors are experiencing a nosedive. Benefits of 3D printing have been noted in academic literature as well as in newspapers [68,69]. Future applications of additive manufacturing are very interesting and promising [70] (Table-2).

Advantages of additive manufacturing together with developments required in future technology to keep on increasing value to companies are well recognized by the businesses. Despite its current shortcomings the technology is here to stay and widely believed that there are applications which are very wide and have potential. Revolutionizing production is appreciated by the private sector, university scholars and governments as technology is largely used for purposes of prototyping. Stakeholders still have a challenge of overcoming restrictions of the technology for it to be used in high volume manufacturing. Small businesses adopting the technology are experiencing significant market growth as the technology becomes more scalable. Manufacturing has become more common and in demand and on this note medical and aerospace industries lead additive manufacturing adoption.

Aerospace industry: In aerospace industry, where consistency and safety is not only a priority but a necessity, additive manufacturing has been quickly adopted [71,72]. As an industry which is heavily dependent on advanced research development, additive manufacturing presented aerospace with a way to prototype new products easily. Bell Helicopter, a leading helicopter manufacturer, used additive manufacturing to prototype different components for their aircraft, but however wanted to begin to use the technology for functional parts. EOS, an additive manufacturing company, assisted Bell Helicopter to design and produced flight certified components for their commercial aircraft. One of the biggest benefits to using this technology was the increased ability to quickly and easily reiterate new designs. Changing the design of a manufactured part usually involves new tool paths, new molds and a lot of money and thus there is no company which gets things right on the first try.

Medical industry: Additive manufacturing has proven to save the aerospace industry a lot of money and time, furthermore millions of lives can be saved in the medical field too. Nanoscale medicine has developed so much complex printed organs should be expected and anticipated in the medical industries.

Challenges of additive manufacturing: There have been drawbacks and challenges that need investigation as well as advanced technological development [73,74]. New opportunities for design and manufacturing have been opened up across different industries by additive manufacturing [75-77]. Many organizations have still not yet rolled out additive manufacturing on a wider scale despite its potential. The challenges of additive manufacturing are facing are multi-faceted but manageable [78,79]. Structure complex with unique geometries can achieve designs which can be customized, with greater efficiencies, higher performance and better environmental sustainability as compared to conventional methods. Certainly, several numerous benefits, such as design flexibility, ability to print complex structures, ease of use and product customization can be associated with additive manufacturing. However, additive manufacturing technology has still not explored enough so that it can be employed in real world applications. There have been drawbacks and challenges which need investigation as well as advanced technological development.

Challenges:

- Post processing, implementation process, materials and quality assurance encompass the technological challenges.

TABLE-2
ADDITIVE MANUFACTURING APPLICATIONS FOR THE FUTURE

Industry	Applications
Health care	Low volume prototyping/manufacturing; partial and full dentures, intraoral scans, dentofacial orthopedics; prototyping; oaths or declaration based parts
Automotive	Tooling and low volume spares; testing new products; fast manufacture of replacement parts for repair shops and rapid prototype
Aerospace	Low volume complex parts; *e.g.* parts produced only when material is required, in shapes only to be produced by manufacturing procedures
Durables for consumers	Parts customized to specific consumers *e.g.* producing your own parts by utilising files and 3D printers thereby lowering freight costs and inventory
Specialist consumer products	Design apparel made with no tooling costs for tooling; jewellery; applications already available: cases for mobile phone; glasses; shoes
Assembly purpose tools	Tooling manufactured easily without costs for setup of manufacturing methods which are traditional
Other	Customized consumer products; applications in all industries besides manufacturing

- Each stage of the design and manufacturing process lacks IT standards and digital threads.
- Not enough well trained skilled technicians and engineers who are skilled, capable of applying 3D printing and familiar with the technology.
- Designers and engineers have rigid adherence to established principles of design with constraints.
- Factors and impacts for business calculation of business cases get very limited consideration.

Although there have been major developments in additive manufacturing technology, a deeper understanding of the manufacturing process and the micro- and macro-aspects of the system [80-83]. New standard additive manufacturing systems and processes need to be developed, with an emphasis on conductive materials, materials with multi-functional characteristics, design of complex multi-material structures, biological applications using cells and biological materials, micro-nano engineering, energy and sustainability The impact on manufacturing makes it an intermediate technology [84]. There is also a need for an additive manufacturing system that can produce large parts for the aerospace and automotive industries. In addition to core industries such as medical, aerospace, military, automotive and consumer products, additive manufacturing technology will also drive the development of other industries in the near future, including dentistry, food, construction, architecture, fashion, toys, home furniture and other beauty accessories [85]. In the printing of customized biocompatible implants and biological tissues, edible foods, customized clothing and jewellery, children's dream toys, embedded conductive parts, *etc.*, new applications may be developed, thus the current pace of research was quickly simplified. It is generally believed that digital manufacturing will become a new field of new technology entrepreneurship and innovation and new technology and innovation will become the most advanced technology in the virtual development of various products and custom manufacturing is becoming popular.

Additive manufacturing's greatest challenges lies in the thinking and reasoning of manufacturers and engineers [86,87]. There must be a shift in how we approach design before the world sees adoption of technology in large quantities. Production capabilities determined the design of products in the past but now it is very crucial to retrain designers and engineers to concentrate on thinking in other terms of design driven manufacturing, which is known to provide degrees of design freedom, which are very high. Once the thought process behind manufacturing changes, only when will additive manufacturing reach its full potential [88-90].

The applicable design procedures and process modelling and control are considered as very important issues that require closer study in the future research. Several research directions have been identified as some of possible research gaps [91], but however until recently, additive manufacturing has not been successful for large-scale industrial applications [92].

Conclusions

Without any shadow of doubt, additive manufacturing technology is transformative and can be used for, scientific exploration and technological discoveries. Additive manufacturing has a huge effect on manufacturing design and this effect will still be growing for decades and this will have an enormous positive impact on the way most innovative companies manufacture their products. Additive manufacturing techniques and methodologies are certainly transformative for manufacturing companies, cutting down on waste, reducing production time and bringing in unmatched efficiencies for product creation. Many companies will still continue to apply additive manufacturing to produce a wide range of limited edition and custom products in the no so distant future.

Smaller companies are now in direct competition with industry giants through the agility brought about by additive manufacturing (AM) printing. Companies have been allowed to improve the quality of their designs, have become more cost-effective and are now able to accelerate the time their products reach to the competitive market thus companies are able to stay relevant in this rapidly changing manufacturing world or whether it is used in prototyping. The de facto method of industrial manufacture in the future has certainly become additive manufacturing.

Novel possibilities of designs together with production paradigms and products have been brought about by advances in additive manufacturing. Even though a considerable amount of research is still needed to make sure that design for Additive Manufacturing is up to speed and growth, both large and small businesses, are adopting and exploring additive manufacturing for end use parts at an impressive and astounding rate. The drawbacks that exist in the current set-up are actually proving to be a source of tremendous opportunity creation. As a result there is urgent need for research and development. Opportunities include development of novel materials, design understanding of additive manufacturing and process monitoring implementation of management techniques of high quality. Rules of product development will certainly be rewritten and new products introduced in this new era, which is beginning and continuously evolving rapidly.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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