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Advance Manufacturing Engineering in the 21ST Century and the Evolution of 3D Printing Materials

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Abstract
In this work a comprehensive study has been carried out on advance manufacturing engineering in the 21st Century and the evolution of 3D printing materials. These are the materials that have made it possible to print different types of products and even specialized components in the 21st Century. The paper has clearly highlighted that the 3D printing technology is a part of advance manufacturing technology a technology that uses computers, microcomputers, microcontrollers, software, to make manufacturing faster, flexible, more accurate and precise, cheaper and economical. The work has taken time to discuss different advance manufacturing technologies and concepts before zeroing down on 3D printing because these technologies are interwoven. The work has mentioned how 3D print was first used to print a cylinder. It all started several years ago perhaps; sparked by Rep-Rap project at the University of Bath (that gave the basics of many of today's desktop 3D printing devices) and the rise of Brooklyn's Maker-bot (now part of the Strata-sys empire). 3 D printing has since then developed very fast, and keeping pace with materials development. There are different types of 3 D printers today with each type having its own printing materials. This study has shown that over the years there has been a great evolution of 3 D printing materials that has covered a wide variety of materials. Melting point of the material is no longer a limiting factor in the use of materials for 3D printing. This work has clearly discussed the use of innovative materials like plastics, resins, HAP, powders, metals, composites and many others with application in the medical field, household, aerospace, automobile, construction, recreation and many others too numerous to mention here.

Keywords: *Advance manufacturing, 3D printing; Materials; Evolution; Computer; Application; and virtual reality*

1. INTRODUCTION

It is often said that with materials evolution there is no end to technological advancement. This is true because the 21st Century has seen a great development in materials and there has also not been any end in sight for new technologies. We have moved from traditional monolithic materials to synthetic materials, then to advance materials, then to smart and intelligent materials including functional materials (Gandhi and Thompson, 1992; Matthews and Rawlings, 2005; Asuquo, 2021; New Materials, 2020). It is quite interesting to note that the Fourth Industrial Revolution that we are currently witnessing would not have been possible without the advancement made in materials development. The Fourth Industrial Revolution is characterized by advanced manufacturing which uses computers, 3D Printing, CNC machines, robots, and many other technologies. It is the era of Artificial intelligence, machine learning, bock chain, chat bots, and internet of things (Ihom and Offiong, 2018; Asuquo, 2020). 3D Printing, also known as additive manufacturing, layer by layer manufacturing and rapid prototyping technology is making waves in many sectors and fields (Sharma, 2008; Jain, 2009).

Modern foundries have evolved with great precision in terms of castings produced as a result of the introduction or incorporation of the 3D Printing technology also known as additive manufacturing or rapid prototyping technology at the design, mould making, and pattern making stages. Castings are designed using computer software like AutoCAD, Solidworks and others. Engineering drawings are scanned (sliced) by scanner which is a special software, which converts the 3D drawing into a form that is understood by the 3D Printer. Interfacing with the slicing software the 3D drawing is printed by the 3D printer layer by layer until the entire drawing is printed. The printing material used may be plastic, metal, ceramic, etc the printing ink for 3D Printer today has a very wide range and it is determined by the product and the type of machine used for the 3 D Printer. The emergence of this technology has given rise to accuracy in casting production, time saving in pattern making and cost saving in casting production in the foundry of today. Moulds are printed directly using 3D printers for sound casting. The role played by additive manufacturing in foundry today cannot be over emphasized (Ihom, Ocheri, and Offiong, 2014; Upadhyay *et al*., 2017; Ihom, 2022).

A 3-D printer is a computer controlled machine used to produce physical parts from a virtual computer aided model drawing of the object. This machine uses additive manufacturing technology to build an object up, one layer at a time to produce a finish product. It can be used to produce a variety of spare parts and industrial prototypes for hobbyists, domestic and industrial applications and can be employed to create prototypes, foundry patterns, architectural models, and other parts in the educational, scientific and technological sector. Department of Mechanical and Aerospace Engineering, University of Uyo-Nigeria, has employed it to produce body centered cube (BCC) and face centered cube (FCC) structures for instructional purpose in the department. The International Space Technology Center uses it to produce some of their spare parts. Recently a big 3D Printer machine has been developed in Europe that can build or print a complete house in just a few days with just three labourers on site. Today some human body inserts are printed using the 3D Printer, like the medical break-through in South Africa, where a deaf man was cured by repairing his ear drum with a printed ear bone using the 3D printer (Offiong, *et al*., 2019; Tshifularo, 2024; The Largest 3D, 2024).

In the department of Mechanical and Aerospace Engineering, University of Uyo-Nigeria, we are currently involved in research work in the development of 3 D printer and printing materials from recycled waste plastics. However, the crux and kernel of this paper is to x-ray the wide range of 3-D Printing materials in use. As wild as it may sound, today various concrete mix and mortars are used as printing materials for building structures using the 3D printer. The evolution of more 3D printing materials is driven by advance manufacturing as we can see in this paper. This informs the objective of this paper which is to x-ray advance manufacturing in the 21st Century and the evolution of 3D Printing materials.

2. BRIEF HISTORY OF THE 3 D PRINTER

3 D printing technology has come a long way today. The term accurately explains how this technology works to create objects. ‘’Additive’’ refers to the successive addition of thin layers between 16 to 180 microns or more to create an object. In fact, all 3D printing technologies are similar, as they construct an object layer by layer to create complex shapes (http://www.sculpteo.com). The technology all started several years ago, it was sparked by Rep-Rap project at the University of Bath (that gave the basics of many of today’s desktop 3D printing devices) and the rise of Brooklyn’s Maker-bot (now part the Strata-sys empire) Figure 1 below shows brooklyn’s MakerBot 3D printer printing a cylinder http://www.Tpc.com)

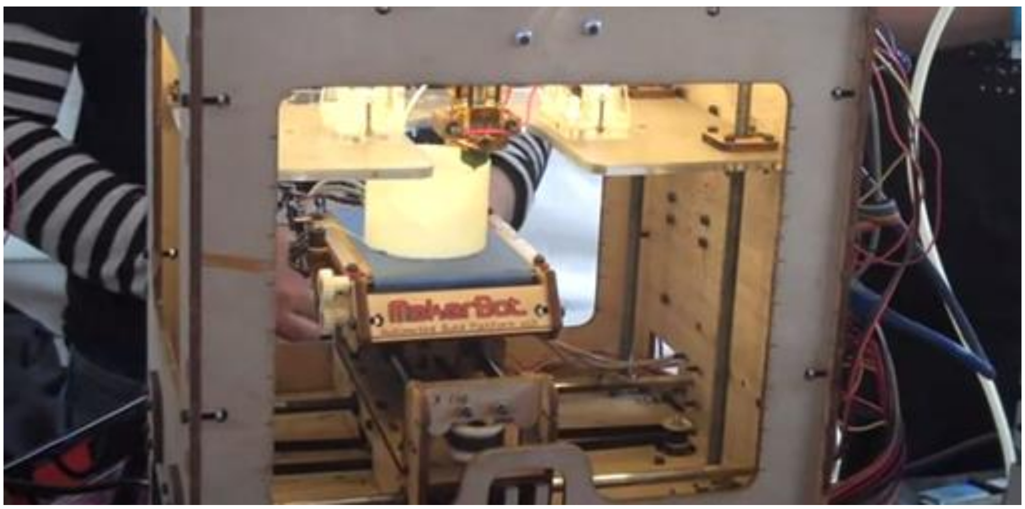

Fig. 1*: MakerBot prints a cylinder, 2010. (only for illustrative purpose) (www. Tpc. Com)*

As patents of early inventors began to expire, there was a boom in entry-level rapid prototyping machines. Of course, rapid prototyping is a term that’s industry specific and the mainstream media needed a new term. Behold, the term 3D printing was born.

Then those working at the more advanced end of the market wanted to differentiate their solutions that were as different from a two grand ABS extruding machine as chalk from cheese. The folks working with advanced laser sintering machines for both plastics and metals, those working on machines that build parts by fusing together powdered titanium, however, did not want their machines to be confused with an inkjet. This class of vendors have also been pushing for the adoption of their machines in the world of manufacturing as an alternative to the likes of CNC machining and injection molding. And so the term Additive Manufacturing was born. And that seems to be how it is now. 3D printing and Additive Manufacturing. Is there any difference between the two terms? The simple answer is that at a technological level, very little – the differentiation is bound up in both the application of the individual process and machine and the end result (Offiong *et al.,* 2019; http://www.sculpteo.com).

A 3D printer could, at the root level, be used to manufacture end use parts. It's all a question of what that part is to be used for. Is it a plastic, low resolution, Yoda head, that's going to be sat on someone's desk? That is a good description of 3D printing. Is it a case for your iPhone that probably cost three times what a properly manufactured one would cost and will last half as long? That also fits 3D printing (Offiong *et al.,* 2019; http://www.sculpteo.com).

Is it an insert for a mold tool that features complex geometries difficult to machine or spark erode and has internal conformal cooling channels that give a better surface finish that will be used 20 times a minute? That's Additive Manufacturing. Is it a new set of components for a helicopter that reduce the tool required and go through a complex process chain of material characterization and post manufacture testing? That's additive manufacturing. The fact remains that the two names are both layer by layer processes (Sharma, 2008; www. Tpc.com, 2018; Offiong *et al.,* 2019).

3. ADVANCE MANUFACTURING

It is said that first industrial revolution was experienced in the eighteenth Century when attempts were made to substitute muscle power by mechanical energy. The world is now passing through fantastic advances, which are occurring continuously in the fields of electronics and computer science, and the computer substituting human brain in the control of machines and industrial processes. The manufacturing scene today is undergoing a revolution. Computer technology offers the means of imparting intelligence to machines (Asuquo, 2021). Computer aided equipment can perform many sophisticated machining jobs at much faster speed and with more consistency and accuracy. Computer-integrated manufacturing promises to boost productivity, in all workshops applications including metal-cutting, material handling, inspection, and assembly (Jain, 2009). A manufacturing system can be defined as a system organized to manufacture parts and products. Manufacturing simply means to produce things. The system takes inputs and produces products for the customer (sharma, 2008) A manufacturing system consists of a group of machines, material handling, storage, and control devices. Advanced manufacturing however, deals more on computer integrated manufacturing (Sharma, 2008).

3.1 Computer Integrated Manufacturing (CIM)

CIM is a recent technology being tried today in most parts of the world not only in advanced countries. It comprise a combination of software and hardware for product design, production planning, production control, production equipment and production processes. It is an attempt to integrate the many diverse elements of discrete parts of manufacturing into one continuous process-like stream. This would result in increased manufacturing productivity, quality, and reduced manufacturing costs. CIM employs flexible machining system (FMS) which saves a manufacturer from replacing equipment each time a new part has to be fabricated. The current equipment can be adopted to produce new part (as long as it is in the same product family), with programmable software and some retooling. Thus, this system has the ability to switch from the machining of one component to different one with no down time for change over. This system requires NC lathes, machining centers, punch presses etc., which have ability to be readily incorporated into multi-machine cell or a fully integrated manufacturing system (Asuquo, 2021).

3.2 CAD/CAM Technology

CAD/CAM (Computer Aided Design/ Computer Aided Manufacturing) technology was initiated in the aerospace industry but it is today being used widely in all industries. This technology is defined simply as the use of computers to translate a product's specific requirements into the final physical product. With this system, a product is designed, produced, and inspected in one automatic process. It plays a key in areas such as design, analysis, production planning, detailing, documentation, NC part programming, tooling fabrication, assembly, jig and fixture design, quality control, and testing. Whenever any deviation is noted, a programmable controller takes automatic corrective action to compensate for the deviation. Thus, a close loop system is formed which produces consistent quality products, reduces waste and improves productivity. Computer technology has become essential for improving performance and safety. Computers help in relaying proper information to the desired place at the proper time and thus avoid malfunctioning and avert catastrophe before it is too late to prevent. CAD/CAM technology can be optimized by using computers to integrate company- wide management of engineering information (Jain, 2009; Asuquo, 2020, Asuquo, 2021).

3.3 Virtual Reality

The technique of interacting with computer have changed from time to time, starting from punch cards to terminal and keyboard to windows operating environment. Virtual reality techniques provide unique way of interacting with computer data and images. These remove the barriers of keyboard, monitor, and mouse and allow user to experience the reality of a computer-generated scene. This would open up new opportunities to expand the use of computer technology for engineers in areas of design, prototyping, maintenance and assembly, factory layout and planning, etc. the graphic models in virtual reality technique appears to occupy three-dimensional space within the viewing area. The natural motions of human (hand and head movement) act as interface to system. A person can look under, around, walk into the computer image of a design. This technology provides immersive, interactive, multi-sensory, viewer-centered, three-dimensional computer generated environment and user gets a feeling of moving around inside and occupying a position in the computer-created world. Objects in the computer environment occupy space and the user navigates through the space as if it were the real environment. The images in the environment change positions as the user moves in the space such as they would change positions in the real world. Sensory inputs are supplied that support the illusion that the user is a part of the computer environment. Thus virtual reality technique offers a new and innovative way to interact with the complex data and designs and presents the opportunity to design in a 3D environment.

Sense of immersion can be created using high-end computers, virtual reality software, visual displays, tracking devices, interaction devices, audio devices, and haptic devices. Head mounted display (helmet) is very commonly used visual display. The helmet contains LCD or CRT Screens, one for each eye. Position trackers (ultrasonic or electromagnetic receivers/transmitters) on helmet provide spatial coordinates to the computer as the user moves around in the space. The spatial coordinates change the image presented in the helmet based on the orientation and location of the user’s head. 3D mouse has also been developed. Instrumented gloves (having sensors for position of hand) are also used to interact in the virtual environment. A unique virtual reality environment is provided by Core Care Automatic Virtual Environment in which stereo computer images are projected on three walls and the floor of a room. Multiple users may be present in the room, but only one person controls the view with a position tracker. Users wear stereo shutter glasses that convert the images on the walls and floors into stereo images. Haptic devices provide the user with information about touching virtual objects. Stereo head-phones mounted in helmet provide 3D sound.

Virtual prototypes can be developed using these techniques and studies like whether a part fills properly, whether the knob or dial is accessible, assessment of visibility, rechangability, accessibility, clearances, comfort, aesthetics can be performed. In this way, need of developing several prototypes is eliminated and significant savings can be realized in design of any machine tool (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com)

3.4 Intelligent Machine Tools

Automated manufacturing systems in order to be successful have to be designed to embody all the local intelligence of craftsmen, programmers, and manufacturing engineers. Knowledge based machining systems are supposed to give a beginner the capabilities of the expert machinist, and to make an existing skilled machinist even more expert by providing rich information about the manufacturing environment (Sharma, 2008).

3.5 Artificial Intelligence (AI)

This enables unattended manufacturing by capturing the craftsman’s knowledge and using it automatically. It utilizes an expert system (computer program) developed from the knowledge of experts. Expert system is a sort of data base of knowledge, together with rules that reflect experience and decision making. The development of expert system is a continuing affair and knowledge about machining process has to be added from time to time to make it more intelligent. The machine tools and factory systems can be controlled automatically when these are designed to have ability to detect and diagnose errors in manufacturing system (Jain, 2009; Asuquo, 2021).

3.6 Computer Controlled Machine Tools

Computers when used for NC part programming offer several advantages over conventional systems. Use of computers refines and improves part programming procedure through interactive graphics techniques. In computer controlled machine tools, the conventional hardware NC Controller unit is replaced by a microcomputer which is used to perform some or all of the basic NC functions by programs stored in its memory. Two types of configurations of computer controlled machine tools are commonly found (i) where a dedicated small microcomputer is used for control of one machine tool (referred to as computer numerical control or (CNC), and (ii) where a large computer controls a number of separate NC machine tools (referred to as direct numerical control or DNC) (Sharma, 2008; Jain, 2009)

3.7 Unmanned Machining

One of the means of increasing productivity is to design unmanned machines. The success of such machines depends upon perfection in two field, viz. automatic tool changer which can handle a variety of tools from different manufacturers, and automatic gauging. Gauging may be done on the machine itself or within the machine at an adjacent station, or at station adjacent to the machine. The parts to be gauged may be transferred to a gauging station within the machine via a loading system, or be moved to an external gauging station by robot (Sharma, 2008).

3.8 Smart Manufacturing

Artificial Intelligence (AI) forms the basic tool for smart manufacturing (Ertel, 2015). AI is a mystifying emerging technology and can be defined in several ways. Some of the definitions used to define AI are:

(i) AI generally relates to the attempt to use computer programming to model the behavioral aspect of human thinking learning and problem solving
(ii) A growing set of computer problem-solving techniques being developed to imitate human thought or decision-making process.
(iii) The area of research concerned with building computer programs to carry out tasks for which a procedural solution cannot be defined in advance.
(iv) That branch of computer science concerned with the study of representation and research.

3.9 Rapid Product Design and Manufacturing

In manufacturing processes, emphasis has shifted from mass production to cost to quality and now to time. Trend is changing from mass production to mass customization. Commitment to time to market strategy has become more common place. It has been observed that significant profits are possible if product can be realized in time so as to establish leadership position, thus enjoying longer life cycle before becoming obsolete. Rapid product design and manufacturing is based on an integrated approach to combine following technologies:

(a) Effective CAD software to capture the intent of designer, modelling and evaluating product performance.
(b) NC machining of modelled objects
(c) Rapid prototype fabrication techniques based on material deposition (material increase manufacturing), instead of conventional material removal or deformation practice.
(d) Conversion technology to make moulds directly for producing functional parts.
(e) Measurement and inspection technologies: CAD/CAM tools integrated into product development system provide powerful aid in rapid product realization (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

3.10 Rapid Prototyping Techniques

In rapid prototyping techniques, real objects are produced directly from parts models in the computer by using additive fabrication techniques like stereolithography for producing polymer based parts, selective laser sintering (SLS) for producing functional metallic parts, spray metal deposition for directly producing the tooling and moulds required to make parts, layered manufacturing technologies (LMT), 3D Printing for producing ceramic moulds, metal dies and end-user parts made of metal matrix composites or ceramics directly from CAD models without intervening step or conversion. These techniques lead to much shorter product development cycle due to: (i) faster and easier production of 3-D Physical prototype for checking the form, function and fit of the new product and parts before finalizing design (ii) feasibility of producing the end-use functional parts directly from the CAD model. Rapid prototyping is the process of rapid creation of a physical solid model from the design data (CAD drawing) without the use of tools or traditional manufacturing processes, thus reducing the cycle time in manufacturing considerably (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

3.11 Stereo-Lithography Technique

Stereo-lithography apparatus accepts surface or solid model CAD data through a file represented in a specific format. The apparatus is programmed to slice (scan) the CAD file into two-dimensional cross-sections of the object using computer generated sectioning process. A bath of photo-sensitive resin is used so that when ultraviolet light strikes it, that position of resin is solidified. The process is repeated, layer by layer, until the three-dimensional object is completely built. Thus through multiple layer solidification, the object is built over a span of time period depending on the resin used, the power of the laser, the exposure time and the configuration of the object. After last layer is completed, the created object is raised above the liquid resin, the excess or trapped resin is drained into the container. Cleaning solvent is used to wipe away any excess resin. The object is then fully polymerized using ultraviolet radiation in a special post curing device (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

3.12 Selective Laser Sintering Technique

In this process a very thin layer of heat fusible powder is initially deposited into a work space container. The layer is then heated to first below its melting point by a heat generating CO_2 laser so that powder particles get fused forming a solid mass. The laser beam intensity is modulated to sinter the powder only in areas defined by the object’s design geometry. Subsequent layers are deposited into the workspace, on top of previous layer, each subsequent sintered layer being fused to the sintered layer below it. Successive layers of powder are deposited and sintered until the part is complete. See figure 2 (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

3.13 Laminated Object Manufacturing

Laminated object manufacturing (LOM) consists of fabricating a part by bonding together layers of sheets (such as metal foil, paper or plastic) in a stack. The machine consists of a platform over which an adhesive backed paper is stretched with the help of two rolls (one feed up roll and the other take up roll) one on either side of the platform. The laser then traces the required shape of the part on the paper. The unused portions are cross-hatched by the laser so that they can be easily removed after the model is completed. After this, the table descends, the paper rolls on, placing the next layer on top of the just completed. The laser performs its function on the new layer. A steam roller is then used to adhere this layer to the previous layer. The cycle is completed until the model is completed (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

3.14 Optical Fabrication

The technique is similar to stereolithography. It uses a visible light argon ion laser. The part is made on a stationary platform. Point-by- point solidification of the liquid take place at the intersection of two laser beams at right angles to each other that is by holographic interference (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

3.15 Solid Base Curing

This method uses photosensitive polymers. The resin in each thin layer is covered with a photomask which is then exposed to UV light and is cured in a few seconds. The unexposed liquid is then removed and the voids are filled with molten wax to support the next layer. The cycle is repeated until the entire part is built up (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

3.16 Fused Deposition Modelling

In this technique, the model is fabricated by depositing very thin layers of molten thermoplastic or wax on top of each other. The filament of the material is fed through a heated extruding head. The molten filament is deposited on a platform to form the part. The process is controlled by a computer which guides a robotic arm to form the 3D part layer by layer. The fabricated part needs no further curing. Figure 2 shows object produced using FDM and SLS technology (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com; http://www.sculpteo.com).

Fig.2. Objects produced using FDM and SLS Technology from plastics and alumide materials (figures are only for illustrative purpose).

3.17 3 D Printing

This technique is similar to the ink-jet printing. A piston supports the power bed. The printer head moves across the bed emitting a continuous stream of droplets of a binder, selectively binding the powder. The piston is lowered incrementally and with each step, a layer is deposited and joined by the binder. After the part is completed, it is removed from the powder bed and the loose powder is removed. It is then heated to remove the binder and is finally sintered. The powders used are: Al_2O_3, SiC, SiO_2, and zirconia. The ink-jet head is guided by a three-axis robot (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com) .

3.18 Photo-Chemical Machining

This process is similar to stereo-lithography, but uses two lasers beams intersecting each other to form the part. One beam moves in the X-Y plane and the other in the Y-Z plane. The process is more versatile and the layer by layer technique is not needed to point the part (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

4. RESEARCH EFFORT IN THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING, UNIVERSITY OF UYO-NIGERIA.

Research effort at the department of Mechanical and Aerospace Space Engineering towards the development of 3 D Printing machine started in 2016. When we had a need to print some crystal structures for instructional purpose for our students offering materials engineering. The teaching of the subject has been a problem because most of the topics were sounding so abstract to the students, particularly the structure of materials and atomic arrangement in this structures. With the first 3 D printer that we were able to develop we were able to use it with plastic filament to print Body Centered Cubic crystal structure (BCC) and Face Centered Cubic structure (FCC) with this illustrative materials the students were able to understand this fundamental aspect of materials engineering.

We then included the processing of waste plastics into filament into the scope of our research, since buying of the imported filament was expensive. We were on this research for some time until in 2018 the department participated in an exhibition organized by some oil companies in Nigeria, at the exhibition AGIP Nigeria Oil Company picked interest in our research work we are today in a research collaboration with AGIP Nigeria Oil company. Fig.3 is a structure donated by AGIP as a 3 D Printing building equipped for our research work. Fig. 4 is an early version of our 3D Printer, the plastic shredding machine, and the plastic extruding machine developed in the department (Offiong, *et al.,* 2019).

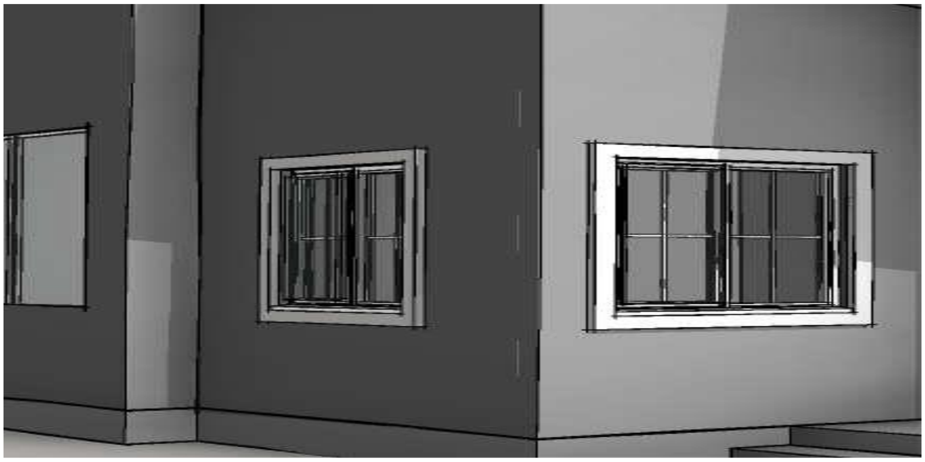

Figure 3: 3D Printing Building at the Department of Mechanical and Aerospace Engineering

3 D Printer | Plastic shedding machine | Filament Extruding machine

Figure 4: the 3D Printer, plastic shedding machine and Filament extruding machine developed at the department.

5. EVOLUTION OF 3D PRINTING MATERIALS IN THE 21ST CENTURY

In the early days of 3 D Printing low temperature melting materials were used for 3D Printing; mostly plastic materials were used. Today the story has changed the material used determine the technology and the type of 3D technology used.

The materials chosen for 3 D printing determine the technology or method used

Plastic or Alumide

- Fused deposition modeling (FDM) Technology
- SLS Technology

Resin or Wax

- Stereolithography (SLA)
- Digital light processing (DLP)
- Continuous liquid interface production (CLIP)
- MultiJet printers

Metal

- DLP technology for silver and brass
- Direct metal laser sintering (DMLS)
- Electron beam melting (EBM)

3 D printing materials can vary widely, with options that include plastics, powders, resins, metal and carbon fiber. These materials make 3 D printing a promising option for many parts, from highly accurate aerospace and industrial machinery components to customized consumer goods (Jain, 2009; Offiong *et al.*, 2019; Https://www.wevolver.com; Https://www.hp.com).
In this section different materials used for 3 D printing are discussed to elucidate on the development of the technology in the 21 Century.

5.1 Bone Replacement Material for 3D Printing

Polymethylmetacrylate is used as cement for bone production in combination with hydroxyapatite (Ca_{10} $(PO_4)_6$ $(OH)_2$) which is a major compound in natural bone. The socket of artificial hip joint is made of high density polyethylene these materials mentioned are used in 3D Printer for the printing of different types of bone replacement in human body. Hydroxyapatite (HAP) is contained in the bone or teeth. The bone contain 65 to 70% and the enamel of teeth contain 95%. In general, HAP powder is formed at room temperature and is used after sintering at about $1000^{O}C$. HAP in the bone or teeth are ultra super fine crystals. Their sizes are about several 10 to several 100nm. Therefore, it is desired that the synthetic HAP crystal should be fine too (Minowa, 2008).

User@ Africa Hub on x (2024) reported that Mashudu Tshifularo from South Africa, he is the first Surgeon on, earth to successfully perform surgery to cure deafness. He created the first in the world invention when he led a team of specialists to successfully reconstruct middle ear implants using 3D printed bones, at the University of Pretoria and Stere Biko Academic Hospital (Minowa, 2008; Jain, 2009; Tshifalora, 2024; Https://www.wevolver.com; Https://www.hp.com).

5.2 Cement, Mortar and Concrete
Cement, mortar and concrete are common materials used in 3D printing. Both mortar and concrete contain cement and various aggregates in different ratios. One of the biggest 3D printer in the world today is used in Europe for the printing of building structures and it needs only a labour force of 3 people on site for the printing of a complete building. Mortar and concrete mix of various ratios are used depending on the specification of the design of the building (The Largest 3D, 2024).

5.3 Plastic Materials for 3 D Printing
Out of all the raw materials used for 3 D printing in the 21^{st} Century, plastic is the most common. Plastic is one of the most diverse materials for 3D Printed toys and household fixtures. Products made with this technique include desk utensils, vase and action figures. Available in transparent form as well as bright colors, plastic filaments are sold on spools and can have either a matte or shiny texture.

5.4 Acrylonitrile butadiene styrene (ABS); is a common thermoplastic polymer. Its glass transition temperature is approximately 105ºC. ABS is amorphous and therefore has no true melting point. ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. Valued for its strength and safety. ABS is a popular option for home-based 3D Printers. It is also referred to ''LEGO plastic,'' the material consists pasta-like filaments that give ABS its firmness and flexibility. ABS is available in various colors that make the material suitable for products like stickers and toys. It is popular among hobbyist printers, but also used in commercially made consumer goods (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

5.5 Glycol-modified polyethylene terephthalate (PETG): Filament creates glossy and smooth-finished printed items that hold their shape well during cooling. It is versatile thermoplastic that combines the ease of use of polylactic acid (PLA) with the strength and durability of ABS. It is gaining popularity in the 3D printing (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

5.6 Polylactic acid (PLA): One of the eco-friendliest options for 3 D Printers, polylactic acid is sourced from natural products like sugar cane and corn starch and is therefore biodegradable. Available in soft and hard forms, plastics made from polylactic acid will likely be common in the 3D printing industry in the years to come. Hard PLA is stronger and harder and more ideal material for a broader range of product (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com) .

5.7 Polyvinyl alcohol plastic (PVA): Used in low-end home printers, PVA is a suitable plastic for support materials of the dissolvable variety. Though not suitable for products that require high strength, PVA can be a low-cost option for temporary-use items (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

5.8 Polycarbonate (PC): Less frequently used than the aforementioned plastic types, polycarbonate only works in 3D Printers that feature nozzle designs and that operate at high temperatures. Among other things, polycarbonate is used to make low-cost plastic fasteners and molding trays. Plastic items made in 3D Printers come in a variety of shapes and consistencies, from flat and round to grooved and meshed. Home craftspeople can even buy polycarbonate spools at most supply stores (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

5.9 Powders

A number of state- of- the- art 3D Printers use powdered materials to construct products. Inside the printer, the powder is melted and distributed in layers until the desired thickness, texture and patterns are made (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com). The powders can come from various sources and materials, but the most common are:

5.91 Polyamide (Nylon): with its strength and flexibility, polyamide allows for high levels of detail on a 3D-Printed product. The material is especially suited for joining pieces and interlocking parts in a 3D-Printed model. Polyamide is used to print everything from fasteners and handles to toy cars and figures.

5.92 Alumide: comprised of a mix of polyamide and gray aluminium, alumide powder makes for some of the strongest 3D-Printed models. Recognized by its grainy and sandy appearance, the powder is reliable for industrial models and prototypes. In powder form, materials like steel, copper and other types of metal are easier to transport and mold into desired shapes. As with the various types of plastic used in 3D Printing, metal powder must be heated to the point where it can be distributed layer-by-layer to form a completed shape.

5.10 Resins

One of the more limiting and, therefore, less-used materials in 3D Printing is resin. Compared to other 3D-applicable materials, resin offers limited flexibility and strength. Made of liquid polymer, resin reaches its end state with exposure to UV light. Resin is generally found in black, white and transparent varieties, but certain printed items have also been produced in orange, red blue and green. The material comes in the following three categories (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com)

5.10.1 High-detailed resins: generally used for small models that require intricate detail. For example, four-inch figurines with complex wardrobe and facial details are often printed with this grade of resin.

5.10.2 Paintable resin: Sometimes used in smooth-surface 3D prints, resins in this class are noted for their aesthetic appeal. Figurines with rendered facial details are often made of paintable resin.

5.10.3 Transparent resin: This is the strongest class of resin and therefore the most suitable for a range of 3D-printed products. This resin is often used for models that must be smoother to the touch and transparent in appearance. Transparent resins of clear and colored varieties are used to make figurines, chess pieces and small household accessories and fixtures.

5.11 Metals

The second-most-popular material in the industry of 3D printing is metal, which is used through a process known as direct metal laser sintering (DMLS). This technique has already been embraced by manufacturers of air-travel equipment who have used metal 3D printing to speed up and simplify the construction of component parts. Metal can produce a stronger and arguably more diverse array of everyday items. One of the main advantages of this process is that the printer handles the engraving work. As such, products can be finished by the box-load in just a few mechanically programmed steps that do not involve the hands-on labor that engraving work once required. The technology for metal-based 3D printing is also opening doors for machine manufacturers to ultimately use DMLS to produce at speeds and volumes that would be impossible with current assembly equipment. Supporters of these developments believe 3D printing would allow machine-makers to produce metal parts with strength superior to conventional parts that consists of refined metals (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com). The range of metals that apply to the DMLS technique is just as diverse as the various 3D printer plastic types:

Stainless steel: ideal for printing out components that could ultimately come into contact with water.

Bronze: can be used to make vases and other fixtures.

Nickel: suitable for the printing of coins.

Aluminum: ideal for thin metal objects.

Titanium: the preferred choice for strong, solid fixtures.

In the printing process, metal is utilized in dust form. The metal dust is fired to attain its hardness. This allows printers to bypass casting and directly use metal dust in forming metal parts. Once the printing finishes, these parts can then be electro-polished and released to the market. Metal dust is most often used to print prototypes of metal instruments, but it has also been used to produce finished, marketable products and field-ready parts. Powderized metal has even been used to make medical devices. When metal dust is used for 3D printing, the process allows for fewer parts in the finished product. For example, 3D printers have produced rocket injectors that consist of just two parts, whereas a similar device welded in the traditional manner will typically consist of more than 100 individual pieces.

5.12 Other Materials

Other materials used in 3D printing include:

Carbon fiber: composites like carbon fiber are used in 3D printers as a top coat over plastic materials. The purpose is to make the plastic stronger. The combination of carbon fiber over plastic has been used in the 3D printing industry as a fast, convenient alternative to metal. In the future, 3D carbon fiber printing is expected to replace the much slower process of carbon-fiber layup. With the use of conductive carbomorph, manufacturers can reduce the number of steps required to assemble electromechanical devices (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com).

Graphite and grapheme: grapheme has become a popular choice for 3D printing because of its strength and conductivity. The material is ideal for devices parts that need to be flexible, such as touchscreens. Grapheme is also used for solar panels and building parts. Proponents of the grapheme option claim it is one of the most flexible of 3D-applicable materials. It is light, strong and very electrically conductive (Jain, 2009; Https://www.wevolver.com; Https://www.hp.com)

Nitinol: this is a common material in medical implants, nitinol is valued in the 3D printing world for its super-elasticity. Made from a mixture of nickel and titanium, nitinol can bend to considerable degrees without breaking. Even if folded in half, the material can be restored to its original shape. As such, nitinol is one of the strongest materials with flexible qualities. For the production of medical products, nitinol allows printers to accomplish things that would otherwise be impossible.

Mould materials: the 3D printing of sand moulds, by binder jetting technology for rapid casting, plays a vital role in providing a better value for the more than 5000 years old casting industry by producing quality and economic sand moulds. The parts of the mould assembly can be manufactured by precisely controlling the process parameters and the gas producible materials within the printed moulds. A variety of powders, of different particle size or shape and bonding materials can be used to change the thermal and physical properties of the mould and hence provide possibilities for casting a broad range of alloys (Upadhyay, *et al.*, 2017)

6. CONCLUSION

The paper advanced manufacturing engineering in the 21st Century and the evolution of 3D printing materials has been researched in details and the following conclusions drawn from the findings:

3 D printing is an advanced manufacturing method that uses CAD drawings to print it layer-by-layer into a physical model

The study has clearly shown that the development of 3 D printing materials has been happening alongside the development of the 3D technology; as diverse as the 3D technology is today so is the materials usage for 3D printing

Research work at the department of Mechanical and Aerospace Engineering, University of Uyo-Nigeria include: developing 3D printing machine and converting waste plastic materials into 3D printing filament.

The work has revealed different types of 3D technologies and the type of printing materials that they use.

The work has shown that today HAP is used for printing of bones, cement and other aggregate mixtures are used in 3D Printers to print houses and other structures.

Finally plastics, resins, powders, ceramics, metals, composites and other materials today constitute the wide array of materials used for 3D printing.

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