International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 05 | May - 2022 Impact Factor: 7.185 ISSN: 2582-3930

A Review paper on 3D-Printing and Various Processes Used inthe 3D-Printing.

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Abstract- This is a review paper on 3D printing and the various materials used in 3D printing and their properties which become a notable topic in technological aspects. First, define what is meant by 3D printing and what is significant of 3D printing. We will go into the history of 3D printing and study about the process of 3D printing and what materials used in the manufacture of 3D printed objects and select the best materials among them which are suitable for our 3D printing machine. Also, see the advantages of 3D printing as compared to additive manufacturing.

Keywords: 3d-Printing, additive Manufacturing.

I.INTRODUCTION

3D printing or additive manufacturing (AM) is a process for making a 3D object of any shape from a 3D model or other electronic data sources through additive processes in which successive layers of material are laid down under computer controls. Hideo Kodama of Nayoga Municipal Industrial Research Institute is generally regarded to have printed the first solid object from a digital design. However, the credit for the first 3D printer generally goes to Charles Hull, who in 1984 designed it while working for the company he founded, 3D Systems Corp. Charles a Hull was a pioneer of the solid imaging process known as stereolithography and the STL (stereolithographic) file format which is still the most widely used format used today in 3D printing. He is also regarded to have started commercial rapid prototyping that was concurrent with his development of 3D printing. He initially used photopolymers heated by ultraviolet light to achieve the melting and solidification effect. Since 1984, when the first 3D printer was designed and realized by Charles W. Hull from 3D Systems Corp., the technology has evolved and these machines have become more and more useful, while their price points lowered, thus becoming more affordable.

Nowadays, rapid prototyping has a wide range of applications in various fields of human activity: research, engineering, medical industry, military, construction, architecture, fashion, education, the computer industry and many others. In 1990, the plastic extrusion technology most widely associated with the term "3D printing" was invented by Stratasys by name fused deposition modelling (FDM). After the start of the 21st century, there has been a large growth in the sales of 3D printing machines and their price has been dropped gradually.

II. PROCESSES

Many different 3D printing processes and technologies have been invented from late 1970. The printers were originally very large and expensive in what they could produce. Many Additive manufacturing processes are now available. Some of the methods melt or soften material to produce the layers, e.g., selective laser melting (SLM), selective laser sintering (SLS), fused deposition modelling (FDM), while others cure liquid materials using different other technologies, e.g., stereolithography (SLA) and with laminated object manufacturing (LOM).

A. Selective Laser Sintering

Selective laser sintering (SLS) was developed and patented by Dr. Carl Deckard and academic adviser, Dr. Joe Beaman at the University of Texas in the mid-1980, under the sponsorship of DARPA.[2] Deckard was involved in the resulting start-up company DTM, established to design and build the selective laser sintering machines. In the year 2001, 3D Systems the biggest competitor of DTM acquired DTM. The most recent patent regarding Deckard's selective laser sintering technology was issued on January 1997 and expired on Jan 2014. Selective laser sintering is a 3D-printing technique that uses a laser as the power source to sinter powdered material (mostly metal), aiming the laser at points in space defined by a 3D model, binding the material to create a solid structure. Selective laser melting uses a comparable concept, but in SLM the material is fully melted than sintered, allowing different properties (crystal structure, porosity). SLS is a relatively new technology that so far has mainly been used for additive manufacturing and for low- volume production of parts. Production roles are expanding as the commercialization of additive manufacturing technology improves.

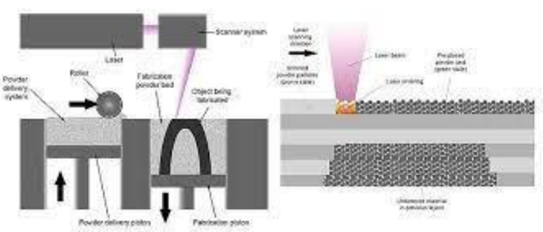

Fig-1 Selective Laser Sintering

B. Fused Deposition Melting

Fused deposition modelling (FDM) method was developed by S. Scott Crump in the late 1980s and was designed in 1990 by Stratasys. After the patent on this technology expired, a large open-source development community developed and commercial variants utilizing this type of 3D printer appeared. As a result, the price of FDM technology has dropped by two orders of magnitude since its creation. In this technique, the model is produced by extruding small beads of material which harden to form layers. A thermoplastic filament or wire that is wound into a coil is unwinding to supply material to an extrusion nozzle head. The nozzle head heats the material up to the certain temperature and turns the flow on and off. Typically, the stepper motors are employed to move the extrusion head in the z- direction and adjust the flow according to the requirements. The head can be moved in both horizontal and vertical directions, and control of the mechanism is done by a computer-aided manufacturing (CAM) software package running on a microcontroller.

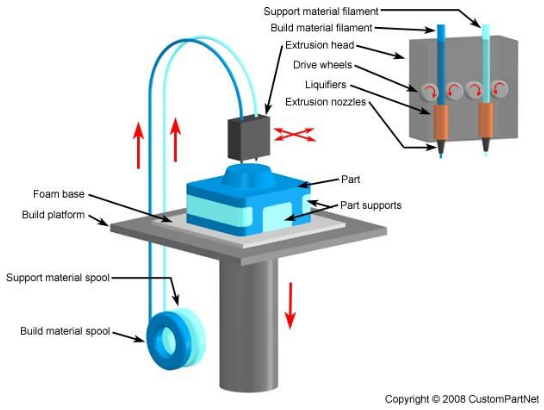

Fig-2 Fused Deposition Melting

C. Stereolithography

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Stereolithography is an early and widely used 3D printing technology. 3D printing was invented with the intent of allowing engineers to create prototypes of their own designs in a more time and in an effective manner. The technology first appeared as early as 1970. Dr. Hideo Kodama Japanese researcher first invented the modern layered approach to stereolithography by using UV light to cure photosensitive polymers. On July 1984, before Chuck Hull filed his own patent and Alain Le Mehaute filed a patent for the stereolithography process. The French inventor's patent application was neglected by the French General Electric Company and by CILAS (The Laser Consortium). Le Mehaute believes that abandonment reflects a problem with innovation in France. Stereolithography is a form of 3-D printing technology used for creating models, prototypes, patterns in a layer-by-layer fashion using photo polymerization, a process by which light causes chains of molecules to link together, forming polymers.[1] Those polymers then make up the body of a three-dimensional solid. Research in the area had been conducted during the 1970s, but the term was coined by Charles (Chuck) W. Hull in 1986 when he patented the process. He then set up 3D Systems Inc. to commercialize his patent.

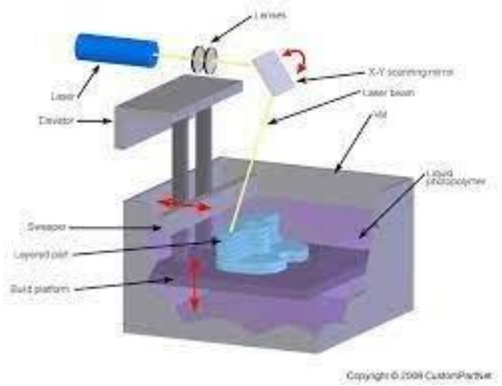

Fig-3 Stereolithography

D. Laminated Object Manufacturing

It is a 3D-printing technology developed by Helisys Inc. (now Cubic Technologies). In it, layers of adhesive-coated paper, plastic, or metal laminates are successively joined together and cut to appropriate shape with a laser cutter. Objects printed with this technique may be additionally modified by machining after the printing process. the typical layer resolution for this process is defined by material feedstock and usually ranges in thickness from one-to-many sheets of paper of a copy.

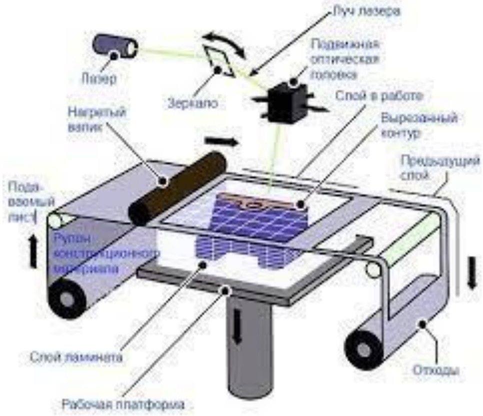

Fig- 4 Laminated Object Manufacturing

III. 3D PRINTER MATERIAL

Following are the materials which can be used with the Accucraft i250 and their properties.

A. Acrylonitrile Butadiene Styrene [ABS]

One of the most widely used material since the inception of 3D printing. This material is very durable, slightly flexible, and lightweight and can be easily extruded, which makes it perfect for 3D printing. It requires less force to extrude than when using PLA, which is another popular 3D filament. This fact makes extrusion easier for small parts. The disadvantage of ABS is that it requires higher temperature. Its glass transition temperature is about 105°C and temperature about 210 - 250°C is usually used for printing with ABS materials. Also, another

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drawback of this material is quite intense fumes during printing that can be dangerous for pets or people with breathing difficulties. So, 3D printers need to be placed in well-ventilated area. Also, good advice is to avoid breathing in fumes during printing considering the cost of 3D materials ABS is the cheapest, which makes it favourite in printing communities until now.

Technical Specifications:

- Density- 1-1.4 gm/cm3
- Dielectric constant- 3.1 to 3.2
- Dielectric Strength [Breakdown Potential]- 15-16 kV/mm [0.59-0.63 V/mil]
- Elastic modulus- 2 to 2.6 GPa
- Elongation at break- 3.5 to 50%
- Flexural modulus- 2.1 to 7.6 GPa
- Flexural strength- 72 to 97 MPa
- Heat deflection temperature at 1.82 MPa -76 to 110°C
- Heat deflection temperature at 455 KPa- 83 to 110°C
- Strength to weight ratio- 37 to 79 kN-m/kg
- Tensile strength: 37 to 110 MPa
- Thermal expansion- 81 to 95 μm/m-K Material Properties of Acrylonitrile Butadiene Styrene [ABS]
- Temperature - 225°C
- Flow Tweak - 0.93
- Bed Temperature - 90°C
- Bed Preparation - apply glue stick 2 layer & then abs glue 1 layer

B. Poly Lactic Acid [PLA]

Poly lactic acid (PLA) (is derived from corn and is biodegradable) is another well-spread material among 3D printing enthusiasts. It is a biodegradable thermoplastic that is derived from renewable resources. As a result, PLA materials are more environmentally friendly among other plastic materials. The other great feature of PLA is its biocompatibility with a human body. The structure of PLA is harder than the one of ABS and material melts at 180 – 220°C which is lower than ABS. PLA glass transition temperature is between 60 – 65 ° C, so PLA together with ABS could be some good options for any of your projects.

Technical Specifications

- Density - 1.3 g/cm³ (81 lb/ft³)
- Elastic (Young's, Tensile) Modulus - 2.0 to 2.6 GPa (0.29 to 0.38 x 10^3 psi)
- Elongation at Break - 6.0 %
- Flexural Modulus - 4.0 GPa (0.58 x 10^6 psi)
- Flexural Strength - 80 MPa (12 x 10^3 psi)
- Glass Transition Temperature - 60 °C (140 °F)
- Heat Deflection Temperature At 455 kPa (66 psi) - 65 °C (150 °F)
- Melting Onset (Solidus) - 160 °C (320 °F)
- Shear Modulus- 2.4 GPa (0.35 x 10^6 psi)
- Specific Heat Capacity - 1800 J/kg-K
- Strength to Weight Ratio - 38 kN-m/kg
- Tensile Strength: Ultimate (UTS) - 50 MPa (7.3 x 10^3 psi)
- Thermal Conductivity - 0.13 W/m-K
- Thermal Diffusivity - 0.056 Material Properties of Poly Lactic Acid [PLA]

- Temperature - 180°C
- Flow Tweak - 0.95
- Bed Temperature - 60°C
- Bed Preparation - apply glue stick 2 layers

IV. APPLICATIONS

1. The Aeronautics and Aerospace industries push the limits of geometric design complexity; the evolution and consistent improvement of the vehicles demand that the parts become more efficient and accurate even as the size of the vessels become smaller. This is why design optimization is essential to the progression of the industry. Optimizing a design can be challenging when using traditional manufacturing processes, and that's why most engineers have turned to 3D Printing.

2. To support new product development for the medical and dental industries, the technologies are also utilized to make patterns for the downstream metal casting of dental crowns and in the manufacture of tools over which plastic is being vacuum formed to make dental aligners.

3. For the jewellery sector, 3D printing has proved to be particularly disruptive. There is a great deal of interest and uptake based on how 3D printing can, and will, contribute to the further development of this industry. From new design freedoms enabled by 3D CAD and 3D printing, through improving traditional processes for jewellery production all the way to direct 3D printed production eliminating many of the traditional steps.

4. Architectural models have long been a staple application of 3D printing processes, for producing accurate demonstration models of an architect's vision. 3D printing offers a relatively fast, easy and economically viable method of producing detailed models directly from 3D CAD, BIM or other digital data that architects use.

5. As 3D printing processes have improved in terms of resolution and more flexible materials, one industry, renowned for experimentation and outrageous statements, has come to the fore. We are of course talking about fashion.3D printed accessories including shoes, headpieces, hats, and bags have all made their way on to global catwalks.

LITERATURE REVIEW

1. Rapid prototyping (RP) have been attracting attention in the manufacturing community because of their capability to reduce the lead time of product development. Present work is an effort to understand the influence of process variables like infill pattern, layer thickness, build orientation and infill density on dimensional accuracy (DA), flatness and cylindricity. Taguchi method orthogonal array L9 was used for the conduction of experiments. MakerBot Replicator2 was used for the fabrication of scaled prototype connecting rod of polylactic acid (PLA) material. DA, flatness and cylindricity of the component were measured by using coordinate measuring machine (CMM). Analysis of variance (ANOVA) was employed to find out the significance of process parameters. A regression model was developed to predict the DA, flatness and cylindricity. The results reveal that the optimum process parameters for the DA, flatness and cylindricity were different. Utility Theory was used to find out the best process parameter condition. The best process parameters for the DA, flatness and cylindricity was found to be layer thickness 100 µm, linear infill pattern, inclined at 45°orientation and 20% infill density. A confirmation test was conducted for checking the goodness of the model, which reveals that results were within the confidence limit.[1]

2. This research paper aims to explore opportunities for weight and cost reduction in the design and development of connecting rods. Two phases are involved in the analysis. The first part is to analyse the loads (compressive and tensile loads) acting on the connecting rod as a function of time to optimize its weight and manufacturing cost using generative design. The generative design is an iterative design process that produces a certain number of outputs based on the power, stress and other constraints applied. The primary considerations are weight, material, and cost for the connecting rod design, we generate which in turn, provides sufficient strength, stiffness, and fatigue resistance. The second part involves the analysis of finite elements that was performed at several crank angles and examined whether the generated designs withstand loads ranging from the tensile load, corresponding to 360 0 crank angle as one extreme load at the maximum engine speed and compressive load corresponding to the peak gas pressure as the other extreme load. Thus, a wide variety of materials are analysed to obtain the costeffective and optimum design of the connecting rod that can be manufactured by additive manufacturing.[2]

3. The use of 3D printing metals has become an increasingly popular manufacturing method in the automotive and aerospace industry, causing a push for faster and cheaper processes. 3D printing has the unique ability to fabricate parts that have been topographically optimized, a method that takes given loads and uses finite element analysis to optimize material layout while maintaining strength. An original and optimized connecting rod will be printed with the selective laser melting and binder jetting processes. Another connecting rod will be machined at the Union College Machine Shop. Weights from the Union College Material Science lab will be used to apply a tensile load on parts, then stress and displacement will be measured. The strengths of different printing processes will be compared and the weight and strength of original versus optimized parts will be compared.[3]

4. This project is to fabricate the most essential parts of Delta type 3D printer parts to make it more efficient in cost and working. This project has 3 vital parts of a 3D printer, and they are Effector, Rod end bearings, Connecting rod (Diagonal rod). The Effector is a component that holds the hot end nozzle and other heat dissipating material within it and we in our project made a multi utility Effector to hold many hot ends such as Laser cutting, CNC tool, Food extrusion and 3D printing hot end. This Effector is also categorized into two as uphold and bottom hold since uphold and down hold. Rod end bearings are the motion transmission bearings that would transmit motion in a spherical path. We have made a different mechanism to transmit the motion same as to rod end bearing by coupling two universal joints and making some modification in it and made it cheaper in cost and efficient in working process. The connecting rod is the linking rod between the carriage and the effector. This connecting rod is used to transmit the motion from the carriage to the effector and this works in accordance with the design imbedded on the printer. The conventional 3D printer has carbon fibre pipes as their connecting rod and in this project this connecting rod is changed to steel and this one is made to withstand the load acting on it and cost efficient. All these parts are connected and made as a single setup and can be used in any delta type 3D printer. The overall cost of this setup is ½ times the cost of the conventional setup.[4]

5. Berman in his paper examined the characteristics and applications of 3D printing for mass customization. He argued that there are several promising applications exist in the production of replacement parts, dental crowns, and artificial

limbs, as well as in bridge manufacturing. 3D printing market allow firms to profitably serve small market segments and enable companies to operate with little or no inventory and significantly reduce the need for factory workers.

6. Singh et al. reviewed the recent technological advancements in materials and in technological aspects of 3D printing, identified future challenges and potential applications in engineering, manufacturing and tissue engineering. Also provided number of patents filed in materials, their applications and industry-wise patent filing trends. Thompson et al. provided an overview of the major advancements, challenges and physical attributes related to Direct Laser Deposition (DLD) process. The Part I focused on the thermal/fluidic phenomena during the powder fed DLD process, which directly influence the solidification heat transfer, which thus affects the part's microstructure and associated thermo-mechanical properties. In Part II Shamsaei et al. focused on the mechanical properties, characteristics, behaviour, and microstructure of parts manufactured via DLD and post DLD process parameters (e.g., heat treatment, machining). Methods for controlling, optimizing the DLD process for targeted part design discussed – with an emphasis on monitored part temperature and/or melt pool morphology.

7. Gibson et al., (2015) presented the work on printing achievements made in AM industry and in development of printing as a process to fabricate 3D parts. They focused mainly on material jetting (MJ) in which all of part material is dispended from a print head. They investigated on material development for printing polymers, metals & ceramics. Material processing fundamentals includes droplet format technologies, continuous mode, & dod mode. Solid scape,3Dsystems, Stratasys are companies involved in development of RP printing industry. They concluded that the AM process include low cost, high speed, scalability. Printing machines are lower in cost than many other AM machines particularly the one that uses laser or electron beams. At present, all commercial MJ machines utilize DOD print heads.

8. Dirk Herzog et al.,(2016), Additive manufacturing of metals, the article describes the complex relationship between AM process, microstructure & resulting properties for metals. This includes the fundamentals of laser beam melting, electron beam melting & laser metal deposition & the available materials for different processes. They presented the microstructures for steel, aluminium, & titanium. They focused mainly on AM specific grain structures resulting from the complex thermal cycle & high cooling rates. They have studied the properties under static and dynamic loading. According to the properties they concluded the applications for the materials.

9. In 2018, T.D. Ngo, done a Research on the Additive manufacturing (3D printing) and made a complete review of the major 3D printing methods using different materials, methods, their applications, and challenges. Materials like Metals and alloys, Polymers and composites, Ceramics are used to find their drawbacks and challenges. Methods of Stereolithography, Fused deposition modelling, Direct energy deposition, Laminated object manufacturing is imposed on various materials to verify the aspects like flexible design. Then Applications, Benefits, Drawbacks, Resolution range (μm), are mentioned in this review. By this, we can Understand all 3D printing concept's, which includes a survey of its benefits and drawbacks as a standstill for future research anddevelopment.

10. S. C. Joshi (2015), has explained that many components of the aircraft can be manufactured using Additive manufacturing with titanium. These components include airframe blades casting, discs, fastenings, and Landing gear. Which uses the Titomic Kinetic Fusion method to print parts and tools for the aircraft. Using this technology, the industry is able to build many complex internal structures for sophisticated rockets and jet Engines. It has also helped in combining many components and make it to fewer components which it turns is Helping in reducing the weight and fuel consumption of the aircraft. In doing so the industry is able to save millions of dollars on each aircraft they manufacture.

11. V. Sreehitha, & M. Petch (2018), presented about the automotive industries print or manufacture

Complex parts, custom tools, spare parts for engines or vehicles with lesser time, and higher precision. Additive Manufacturing can also be used to manufacture parts for old classic cars which or not in stock, where the part can be Scanned and printed right there with flawless precision.

12. J. Norman (2018), Studies states that The Additive manufacturing places an important role in the health industry where the doctors and patients are equally Benefited. Many implants and replacements of body parts like jaw, skull, spine, hip etc. It also helps pharmaceutical industries to fabricate drugs of multidrug combination and of specific dosages and helps in experimenting with those drugs on printed organs.

CONCLUSION

It was concluded that Acrylonitrile Butadiene Styrene is the strongest 3D printing material which can carry a load of 47 KN up to Yield stress. FEA results shows that Acrylonitrile Butadiene Styrene is strong when subjected to tensile or compressive loading. These types of 3D printed components can be used when there is customized requirement. This will result into reducing the time of Production, complex designs can be manufactured and avoids the cost of moulding. This concept of Advance manufacturing can be used for different mechanical parts manufacturing like gears and Mould manufacturing for composite materials. These types of manufacturing can be used in Biology where 3D printed body parts can significantly enhance learning. Feeling the texture of a brain is different from seeing it in a book or on screen. Complex structures of protein molecules in DNA can be very easily appreciated with 3d prints.

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