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Review on History and Advancement in Additive Manufacturing

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Abstract

Additive Manufacturing is rapidly emerging technique that benefits production of object by deposition of materials. Materials can be deposited layer by layer or materials can be directly cured using light or other sources discussed in this paper. This paper studies history of Additive Manufacturing, methodology of different types of newly emerging techniques in additive manufacturing field like medical fashion food and many other industries. Process materials and their scopes in respective field are discussed. Different substitute materials that can be used in photo polymerization process are also discuss in this paper.

Keywords: Additive manufacturing, 3D printing, Bioprinting, Photopolymerization

Introduction

Additive manufacturing is process of building object by depositing materials layer by layer on platform. This process is done using computer aided design (CAD) data. It can be also called as 3D printing.

Stages involved in Additive:

A. **Conceptualizing and preparing CAD Model**: Digital model of object that is to be manufactured is produced in CAD software

B. **Converting into STL file format:** Surface of object bill on CAD is then converted into series of linked triangles to recreate solid model and is converted to stereolithography file format.

C. **Correction in STL and transferring:** Problems like double triangle, missing triangles or gap may arise which will affect surface of the manufactured object so the file is first check and then transferred to the machine.

D. **Machine setup:** materials that will be used in manufacture is loaded and proper setup is done to achieve accurate and desired print.

E. **Building object**: based on STL file format data, object will be built on the platform

F. **Building removal:** after completion of process and proper curing build is removed from the platform by taking proper care for further post processing.

G. **Post processing:** post processing if required is done in this phase. Cleaning polishing or applying anti corrosion material is done in this phase.

H. **Application:** Material is ready to use.

Types of Manufacturing Process:

1. **Subtractive Technology:** Removing layers of material to obtain required dimension of object
2. **Additive Technology:** Adding layers of material to obtain required dimension of object

3. **Joining Technology:** Joining layers of material to obtain required dimension of object
4. **Dividing Technology:** Opposite of joining process is dividing process
5. **Transformative Technology**: Is process of obtaining newer object form a single workpiece, without affecting mass of workpiece. Done using forming process or by heat treatment.

II. CATEGORIESOF ADDITIVE MANUFACTURING:

AM process is categorized into seven types (ASTM 2010):

1. Polymerization: this process works on principle of layer-by-layer curing surface to form object. Materials used here are polymers are reason which are mixed with photo initiators. This material solidifies when comes in contact with light of specific wavelength. Tank full of photo polymers is used and light source is scanned and allowed to fall on polymer. First layer is formed and platform is allowed to move down and after that another layer is formed following the same process. This process has high accuracy and is capable of producing objects with good surface finish but this process requires was processing.

III. PHOTOPOLYMERIZATION TECHNIQUE

Photo polymerization technique uses racing which contains photo initiators and in presence of oxygen can be used to manufacture and object by layer by layer deposition of materials on platform. Specific wavelength visible or UV light can be used to cure the resin.

This process can be categorized in three types;

1. Vector scan : layers form by scanning polymerized point
2. Digital light processing : layers are formed at once by projecting section
3. Two-photon method: micro metric objects are formed by 3D scanning of polymerization point generated at intersection of two light sources.

Based on direction of part build,

1. Up to down
2. Down to up

[1] The case study is based on photopolymerization process to find out alternative for the materials that can be used to build the part. Five materials having different composition where taken for the study. All these materials has viscosity of 140 - 550 cP at temperature of about 25 +- 5 degree.

(Refer Figure 1)

3D printer called hunter developed by Flashforge corporation was used to build part. 405 nm LED light source was used to cure the material. Attention test compression test and flexural test was done on the path build using all the five reasons.

Tensile stress test result:

It was found that resin 1 has maximum tensile strength of 53 MPa and modulus of elasticity of 3 GPa. Resin 2 has maximum tensile strength of 50 MPa and modulus of elasticity of 3.2 GPa.

Compression test result:

Resin 1 has maximum ultimate compression stress of 110 MPa and Resin 2 has maximum ultimate compression strength of 84 MPa.

Flexural test results:

Resin 1 has highest maximum stress of 75 MPa and maximum strain of 5% and reason to has maximum stress off 65 mph and maximum strain of 4%. It was found that resin 5 has least value in all three test.

We can conclude that raisins having high

amount of inorganic additive has high tensile stress elastic modulus compression in stress and high hardness. In coming days this materials can replace commonly used materials like ethylene glycol diacrylate and EGPEA.

(Refer Figure 2)

1. Material Jetting: this process works on principle of layer by layer forming object where liquid resin or photo polymers are heated at 30-60 °celsius to achieve the required viscosity. Virtue required viscosity the material is preheated and then with help of print head or nozzle is sprayed. Small droplets of photopolymer r-squared over the surface at desired location and UV light is used to cure the material. Layer by layer materials are deposited. Once first layer is is form the platform is allowed to move one layer down And the another layer is build. This process allows use of multiple colour materials and causes less wastage but parts produce using this process has poor Mechanical properties.
2. Binder Jetting: this method works on principle of cheating powder material layer by layer to form object. Binder materials are used by two consecutive layers. This works in similar fashion of today inkjet printers printer head that has powder material sprays material on the platform and formed the initial layer. Two layers are bind by using binder materials. Process continues until enter object is formed. Multiple colours can be used to build object by using different materials of ceramic polymer or metal. Post processing may be required and this object's build by binder jetting are not suitable for structural parts due to presence of binder material.
3. Material Extrusion: this process works on principle of layer-by-layer deposition of material over platform until full object is build. Materials in form of filament i.e; acrylonitrile butadiene styrene, polycarbonate, polylactic acid etc are used. Filament mills in extraction chamber and with their of nozzle is made to fall on desired location so as to build object. Multiple colour filaments can be used to obtain different colours of object. One layer is deposited on platform and platform is allowed to move one layer downwards so that another layer can be deposited. This process is simple, less on cost and faster fabrication. Fully functional objects can be produce but accuracy and speed of building and object is very low.
4. Powder Bed Sinterring Techniques: this process works on principle of layer-by-layer depositing powder material on the platform at desired location and curing it using laser. Binder material is first heated at temperature just above the melting point to avoid problems associated with distortion and to bond layers. First layer is formed and platform is allowed to move downward at thickness of one layer. Similar process is is repeated to form other layer. Materials that can be used are powder form of polymers metals alloys etc.
5. Sheet Lamination: this process works on principle of layer by layer forming. Sheets are cut using blades are laser to obtain desired shape. Depending on object different shapes of sheets are cut. All seats are binded using binder materials are heating roller or by applying glue. This method can be classified into two types 1. Form –then - bond where one-by-one layers are cut and glued together; 2. Bond – then – form where whole sheet is bonded using blue forming a solid structure and then with help of laser or blade is cut into the required shape. Process is economical and faster as no residual stresses are found in modal but this process may required post processing.

6. Direct Energy Deposition Technique: this process uses materials like metals ceramics and polymers to form object by depositing layer by layer material on platform where it's already files to form object. Materials are melted and deposited at desired location. Generally layers of 0.25 mm to 0.5 mm thick are form. This can be used to build a repair functional parts. This process sometimes need post processing.

IV. HISTORY OF ADDITIVE MANUFCTURING

History of Additive Manufacturing can be subdivided into three parts;

(Refer Table 1)

V. ADVANCEMENTS IN ADDITIVE MANUFACTURING:

Computer axial lithography: [2] In 2017 UC Berkeley and Lawrence Livermore developed a new technique of building object using a light source (Projectors). They used mixture of liquid gelatinmethacrylase hydrogel and photoinitiators gel was kept at room temperature and in presence of oxygen the process was done. Projector projects light on the reason and in presence of photo initiated gel gets materialised and exact object was formed. Layer-by-layer deposition may need post processing but in this method exact thing was produce and there was no need of post processing. City scan process was used to get dimensions of complex parts and the exact image was loaded in projector and then projected on the gel. A mixture of Jail consists of 75% bisphenol A glycerolase, 24.6 percent of polyethylene glycol diacrylate and point 4% of photoinitiators were used.

Ceramic omni-directional bioprinting: [3] broken bones in old age or tooth don't heal so there is need to implement them artificially. Materials used in this process includes calcium phosphate which is main material found in bone and teeth in presence of living cell. Process take place in water bath having gelatin support structure. When mixture of calcium phosphate and living cells comes in contact with water living cells starts multiplying and forms network of tissues which acts as a binder of compounds of calcium phosphate. The small crystals are form and does enter parties build. At higher temperature the support structure made and does the parties obtained.

Freeform reversible embedding of suspended hydrogel (FRESH): [4] This is new and underdeveloped technique of bioprinting structure of human heart. Human heart has strong flexible and squishy material tissues. Materials like alginate made of seaweed was discovered to have properties of printing. So it was used to build complex structure of human heart. This process was done in gelatin support. A needle nozzle moves in this gelatin bath extruding alignate to produce required structure. This bill part is allowed to cure at 37 degree Celsius for about 24 hours in incubator so as geleatin support structure melts and build object is obtained. It is complicated to build multi-compartment of things like hard and there is much higher chances of puncture and breaking. To overcome such problems this method is under development.

Rapid liquid printing: liquid bath of resin is used to build part where there is no need of support structure. It is like drawing in space. They use liquid resin which is not specified oxygen to build the part in presence of chemical as a curing agent or can be photo cured by single laser beam method, masked lamp method, or two laser beam method. There is no scale limitation as different size and dimension of part can be manufactured using this process.

Adidas and Carbons collaboration: [5] Carbons in collaboration with Adidas has build a 3D printer machine to build customized shoe sole for athletes. Liquid bath of reason in presence of photo initiatives and oxygen were used to build sole. There is no need of support structure. Entire path was built from down - up system. Based on pressure points of individual customer sole and lightweight shoe can be made. This is limited edition thing and more information is not available about materials used.

Vegan food: [6] as per requirement of individual custom made food rich in protein and essential oils with less cholesterol rate can be produce.

Spanish farm Novamate has developed a 3D printer to build vegan food. Vegan food is the food made from plant extract. They identified three main components of food that is muscles blood and fat to make perfect vegan food by using plant extract. The claim that transferring to vegan food will reduce CO2 emission up to 8 billion tonnes year. Israeli company may take is also doing research on same thing.

Direct Energy Deposition: [7] Discussed four techniques for DED,

1. Wire Arc additive manufacturing
2. Laser fed with wire
3. Electron free form fabrication
4. Laser fed with powder

The mainly focused on laser fed with powder process to manufacture aircraft part. In this source laser beam and material nozzle are attached together. Material form No 16 falls at desired location and lazer its it to solidify. As compared to other mention process a good accuracy surface finish and thinner layer can be achieved. Initially 1 cad file is produced which is decomposed into four main parts that is,

1. Main body
2. Diffuser
3. Rim
4. Six boxes

Which is then converted to an neutral step file so that it can be read in any simulation software. Slicing is done and parameters of part and Path of part are planned. The path generated is then converted to a MMF which is checked in simulation software to pre-determined critical areas and to work on them. If satisfactory results are obtained then paath simulation is done and robot code is generated. 6 Axis robotic arm was used which has lazerhead as end effector. Abil platform was to excess position which rotates part during process of building. Material used was powder of stainless steel 316 in presence of argon gas.

VI. APPLICATION:

1. Aerospace and Automotive Industry : Complex and Light weight material can be used to produce parts.
2. Medical Field : Bones, 3D skin, drug and pharmaceutical research, bone and cartilage, replacement tissues, organ can be produced.
3. Rockets : A Three, 6 DOF robots was used to build entire robot in 60 days. One robot was used for building and other two for post processing. Robot was able to access to move about 14 feets radius of its centre
4. Electric and Electronics Industry : Electronic like silicon-controlled rectifiers, transistors, diodes, operational amplifiers, light-emitting diodes (LEDs), batteries and so on can be mass produced using 3D prining.

VI. CONCLUSION:

1. Based on case study of Photo Polymerization we can draw conclusion about finding different resin which can replace traditionally used material in AM.
2. It can be observed that resins with higher amount of inorganic Additives has seen to have better properties.
3. Traditional technique involves layer by layer deposition of materials to build a object which is time consuming and costly so researchers and company collaboration worked to build methods so that complete object can be created at one go without need of much post processing and loss of material.
4. And this method are used to build custom made products which is difficult to produce traditional or by earlier AM methods.
5. Further research to get more accurate and faster results is on its way. This methodwill soon get available for different businesses.

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LIST OF FIGURES:

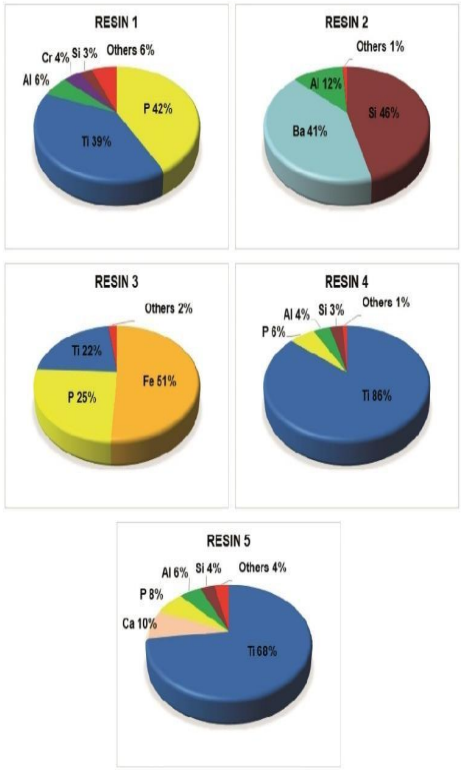

FIG 1. COMPOSITIONS OF RESINS

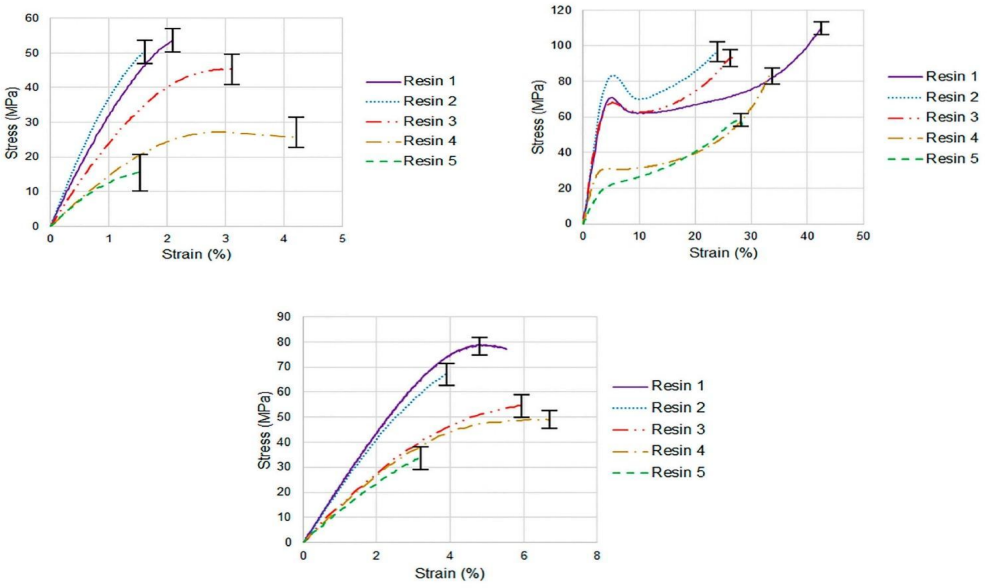

FIGURE 2. TENSILE, COMPRESSION AND FLEXURAL TEST RESULTS

LIST OF TABLES:

YEAR	DEVELOPMENT	DESCRIPTION
1980	First patent for Rapid Prototyping Technology was filed	Dr Kodama, in May 1980 filed first patent for Rapid Prototyping Process.
1984	First patent for SLS apparatus was filed	Charles Hull, in 1984 filed first patent for stereolithography apparatus
1986	First patent for SLA apparatus was issued	Charles Hull, in 1986 was issued patent for stereolithography apparatus
1987	Stereolithography(SLS–1) was introduced	It is layer-by-layer process of which uses UV laser to harden light sensitive liquid resin to build a 3D object.
1987	First patent for SLS technology was filed	Carl Deckard, in 1987 filed first patent for stereolithography technology
1988	Development of first Acrylate Resin	3D Systems and Ciba-Geigy together developed first Acrylate Resin
1989	First patent for SLS technology was issued	Carl Deckard, in 1989 issued first patent for stereolithography technology
1990	Electro Optical Systems (EOS)	A German based company EOS sold its first Stereos stereolithography system
1991	FDM, SGC and LOM Process were commercialized	FDM (Fused deposition modelling) uses thermoplastic material which is deposited layer-by-layer on platform to build 3D object SGC (solid ground curing) uses UV light source and light sensitive liquid polymer to build 3D object on glass platform LOM (laminated object manufacturing) sheets are bonded together and cut into desired shape using laser to obtain required 3D object
1992	Patent for FDM technology was issued	Stratasys, in 1992 issued first patent for FDM (Fused deposition modelling) process
1992	Development of Selective laser sintering (SLS) and Soliformstereolithography system	SLS process uses heat from laser to solidify powdered material to obtain required 3D object
1993	Commercialisation of DSPC process	DSPC (direct shell production casting) uses printer inkjet mechanism. Binder material mixed with ceramic powder were deposited on desired location to build a 3D object
1996	Introduction Genisys machine	Stratasys, in 1996 introduced Genisys machine which worked on extraction process similar to FDM

1996	3D printer Actua 2100 was sold	This printer uses was to build object. Was as a material was deposited layer-by-layer on platform with aid of ink jet mechanism.
1996	3D printer Z402 was launched	This printer used starch and plaster based material mixed with water based liquid binder.
1997	Introduction of Laser additive manufacturing (LAM) process	AeroMet , in developed LAM process which uses titanium material and with aid of high power laser required 3D object was obtained
1998	Commercialisation of laser engineered net shaping system	Optomec developed LENS system at Sandia National Labs.
2000	Introduction of 3D inkjet printer	3D printer called Quadra, which has,1536 nozzles in presence of UV light source for material deposition was introduced.
2000	Introduction of PatternMaster	Machine used to make wax moulds was introduced by Solidscape.
2000	Introduction of DMD process	Direct Material Deposition process was introduced by Precision Optical Manufacturing (POM) which was used to build or repair object.
2000	Introduction of Prodigy	Machine that uses ABS plastic material to build object was introduced in July 2000.
2001	Development of SLS process for non-liquid photocurable materials	OptoForm, French company developed this method which can use different materials like ceramic, metals, composite material etc
2002	Sell of first Variable Lamination Machine	Menix , a Korean company sold its variable lamination machine VLM300
2004	Introduction of Vanquish photopolymer based system	Envisiontec, introduce a system that helps to solidify entire layer of deposited material at once
2005	Colour 3D Printing System	Z.Crop, introduced a colour 3D printer at cheap rates which were capable of building large volume of products, with good quality
2009	ASTM Committee F42	Published terminology for industry
2009	Introduction of automated monochrome ZPrinter 350	Z.Crop Introduction of automated monochrome ZPrinter 350 which was capable of automatic loading of material.
2009	Introduction of two plastic laser sintering machine	EOSINT P 395 and EOSINT P 760
2009	Introduction of ProJet 5000	3Dsystem, introduced machine that uses VisiJet MX Photopolymer material to build a 3D object.

2011	Introduction of new crossover AM Machine	Stratasys , introduce Fortus 250 machine which uses ABS material with soluable support material
2012	3D printed photo reliefs	BumpyPhoto, Poland company uses digital photograph to develop 3D height field and using that object is printed in 24-bit colour on ZPrinter