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A Review on Diverse Materials Applied for Additive Manufacturing

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ABSTRACT

Additive or constructive manufacturing is a manufacturing technology in which prototypes and functional parts are built through layer by layer addition of material directly by importing the STL file from CAD software to 3D printer. Unlike many manufacturing processes in which material destruction or erosion takes place in this technology material is successively added in a constructive manner to obtain physical 3D object. Due to its simplified product development process it has a wide range of applications in many distinct areas like Automobile, Aerospace, Architecture, bio medics and consumer goods. Since inception many additive manufacturing techniques were evolved and a variety of materials from the classes of metals, polymers, ceramics and composites are utilized. As the numbers of applications are increasing day to day the development of new materials has gained significant importance. In the current paper an over view of developed materials for additive manufacturing processes are reviewed and recent research developments in natural, diverse materials for additive manufacturing applications are discussed.

Introduction

Additive manufacturing or otherwise termed as rapid manufacturing is a three decade old technology in which powder or plastic is added in the form of layers to produce parts .At beginning in the early 1980s this technology was only confined to build prototypes so it is termed as “rapid prototyping” but due to recent technological and material advancements additive manufacturing was enabled to produce final end use products.

In the process of additive manufacturing the construction of physical models is carried out by exporting virtual design from a computer which is called as CAD data. The CAD file is converted to STL format which in turn sliced in to thin horizontal cross sections virtually and then fed to a 3D printer to produce final object. The primary advantage of producing parts through additive manufacturing is that it can produce parts of complex geometrical shape and feature. Other benefits like simplified product development cycle, least material wastage and increased efficiency of parts produced can be achieved by this technology.

Additive Manufacturing Technologies

There are a number of technologies which comes under additive manufacturing some of the most prominent and well known technologies are stereo lithography(SLA), Fused deposition modeling(FDM), Selective laser sintering(SLS), Selective laser melting(SLM), Direct metal laser sintering(DMLS), Laminated object manufacturing(LOM) , Three dimensional printing(3D printing). Still a lot more technologies are evolving day to day. Stereo lithography (SLA) was first additive manufacturing process developed in 1986 by Charles W.Hull and commercialized by 3D systems. In this process a photopolymer "resin" is used to build part layers in the presence of a laser beam. For each layer, the laser beam traces a cross-section of the part pattern on the surface of the liquid resin which is exposed to ultraviolet laser light and hence cured and solidifies the pattern traced on the resin and joins it to the layer below. Fused Deposition Modeling (FDM) is a process, in which plastic or wax material is extruded through a nozzle that traces the parts cross sectional geometry layer by layer. The build material is usually supplied in the form of filament. This process was developed by “Stratasys” in Eden Prairie, Minnesota.

Selective laser sintering (SLS) was developed and patented by Dr. Carl Deckard and academic adviser, Dr. Joe Beaman at University of Texas at Austin. This is a Layer Manufacturing process that allows generating complex 3D parts by consolidating successive layers of powder material on top of each other. The Consolidation or curing is done by a laser beam.

Direct metal laser sintering (DMLS) is a process developed by a German firm by name “Electro optical systems” (EOS). This is very similar to selective laser sintering in this method only metal powders get fused into a solid part through melting locally under the focused beam of laser. This process is very much feasible to produce complex geometries.

Laminated object manufacturing (LOM) is suitable for laminates having very thin cross section like paper. In this process profiles of objects are cut by using CO2 laser, the paper gets unwound from a feed roll onto the stack and gets fixed to the previous layer through bonding using a heated roller. The roller melts the coat of plastic on the bottom side of the paper to create the bond. Hence this process is repeated to create a solid object. The concept of LOM was not much effective when compared to other AM techniques as a result of this Helisys the commercial provider of LOM process stopped its operations in the year 2000 but 3D systems is still working for development of this process Three Dimensional Printing (3DP) process is a MIT-licensed process in which water-based liquid binder is supplied in a jet onto a starch-based powder to print the data from a CAD drawing. The powder particles lie in a powder bed and they are glued together when the binder is jetted. This process is called 3DP because it is similar to Two Dimensional printing with inkjet printer on a paper. Wide range of polymers can be utilized in this process.

Materials for Additive Manufacturing

Materials play an important role in understanding the relationship between component manufacture and performance of end product. With the wide ranging possibilities inherent in AM produced components, a fundamental understanding of the

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Process /structure/property relationships across different material systems is necessary. The materials used for AM processes are categorized in to four types.

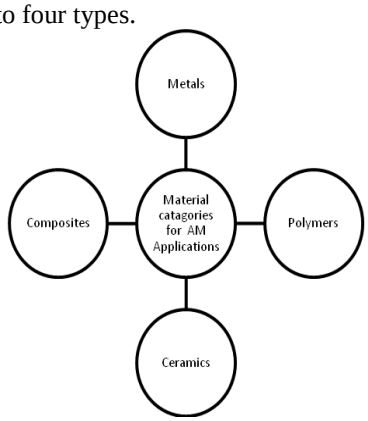

Figure 1. Material categories for Additive manufacturing

Metals

Metals are the most promising materials used in Additive manufacturing processes. In most of the cases metals are used in powdered form particularly in processes like SLS, SLM and DMLS. Some examples of metals used in AM processes are Stainless steel GP1, Cobalt chromeMP1, titanium Ti6Al4V, Ti6Al4V ELI and TiCP, IN718, AlSi20Mg, maraging steel MS1,IN625,IN617, aluminum 4047, Cu-Ni alloy, titanium TiCP, Ti-6-4, Ti-6-2-4-2 and Ti6-2-4-6,steel H13[7].

MikeShellbear and Olli Nyrhila of Electro optical systems (EOS) Germany proposed Direct metal20 a Bronze nickel based multi component metal powder which can be processed with minimal layer thickness as low as20µm.

EOS stainless steel PH1 is a material provides high yield strength (approx 1025Mpa) and hardness (30-35HRC).

EOS Titanium Ti64 is a light weight pre alloyed Ti6Al4v alloy having good mechanical properties and corrosion resistance for DMLS process [4]. EOS-CobaltchromeP1 is cobalt chrome molybdenum based super alloy exhibits excellent mechanical properties like ultimate tensile strength greater than 1150Mpa and hardness 35-45HRC[4]. Laser formA6 steel material of 3D systems used especially for selective laser sintering exhibits hardness 20-40HRc, shows 2x thermal conductivity faster molding cycles for increased productivity. Other similar material Laser form ST-200 is a special stainless steel composite used to produce durable and dense metal parts, such as tooling inserts.

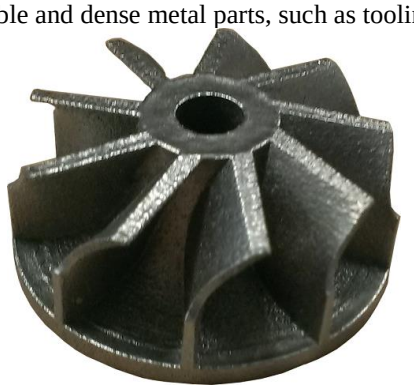

Figure 2. Laser sintered Metallic components

Laser form ST-100 material is also a powered stainless steel from 3d systems with high durability used to produce prototypes and metal mold inserts [6].

Polymers

A polymer is a large molecule having large number of repeated structures. Polymers generally comes under molten metal system of materials for AM processes Thermoplastics are most widely used polymeric materials in processes like FDM. Due high environmental sustainability and no appreciable warpage and shrinkage polymers have huge chances for application in AM processes Some of the most prominent polymers are ABS(Acrylo nitrile butadiene styrene), PLA(Poly lactic acid), Polyethylene, Polypropylene, PA(polyamide), polystyrene etc. Several new versions of polymers with increased functionality came in to existence like, ABS-M30 with properties like high tensile, impact and flexural strength, 25-70 percent more stronger than standard ABS material. ABS-M30i is a bio compatible and standard material for medical and pharmaceutical applications.

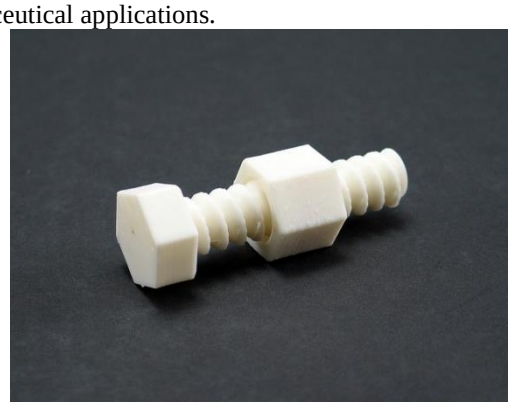

Figure 3. Thermo plastic components

ABS plus thermoplastic is 40 percent more stronger than standard ABS material and posses high environmental stability. ABSi is thermoplastic translucent material having good mechanical and aesthetic properties. PC (Polycarbonate) is highly used industrial thermoplastic having superior mechanical and thermal properties. ABS-PC material has both the properties of ABS and Polycarbonate. PPSF/PPSU (Polyphenylsulphone) is a thermoplastic material having high heat and chemical resistance of all FDM materials. ULTEM 9085 is a strong, light weight, flame retardant thermoplastic material especially used in aerospace and marine applications[1]. PEEK(poly ether ether ketone)is a chemically inert high strength polymer with excellent mechanical and thermal properties which shows resistance to certain factors like creep ,high temperatures ,radiation etc. PEEK can be applied in medical industries for the manufacture of implants and tissue scaffolds [9].

PMMA (poly methyl methacralate) is a kind of linear thermoplastic polymer having high strength, young modulus and resistance to rupture. This hard thermo plastic is highly scratch resistant and exhibit less moisture absorption capability. PMMA material has applications in medical and pharmaceutical industry [10]. Accura25, AccuraPPwhite(SL7811), Accura ABS white (7870),Somos10122,Somos11122,Somos18120 Protogen O-XT are some of the photo polymer resins used in stereo lithography process.

Ceramics

Ceramics are one of the hard, high temperatures resistant and brittle in organic materials used in AM processes. These materials have high compressive strength and exhibits thermal and chemical resistance. Ceramics can be applied to FDM process in which ceramic loaded polymer filaments are used to produce parts and this process is termed as fused deposition of ceramics (FDC). Attempts have been made by using ceramic powders in selective laser melting (SLM) process in which ceramic powders are directly melted to produce complex geometries. Some of the basic ceramics used in AM processes are alumina, silica, zirconia Si_3N_4 ZrB_2[8].

Hydroxyapatite is a bio compatible ceramic having porous structure suitable for fabrication of tissue scaffolds. Lead zirconate titanate (PZT) is a another kind of advanced ceramic use especially for industrial application Ti_3SiC_2, a new class of

ceramic used to build fully dense parts with good electrical and mechanical properties. Envisiotec Nanocure RC 25(87% ceramic filler) is a ceramic and glass filled resin used in Stereolithography process[8]. Aluminum Nitrate, Mullite and Cordierite are some of the ceramic materials used by cerampilot in France for the manufacture of industrial, electronics and biomedical goods [8].

Figure 4. 3d printing of Ceramics

Composites

Composites are or naturally occurring or artificially engineered materials made from two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct at the macroscopic or microscopic scale within the finished structure but exhibit properties that cannot be achieved by any of the materials acting alone. For FDM process composites from classes of Polymer-metal, polymer-ceramic, short fiber-reinforced composites can be utilized. FDM filament made from the iron–nylon combination is a Polymer-metal composite material proposed by a researcher at Swinburne University [8].ABS-iron is another polymer-metal composite founded for FDM application.

Coming to SLS and SLM processes, composites with combination of metal-ceramic (WC-Co, WC-CuFeCo, WC-Cu, ZeB2-Cu, and TiB2-Ni), ceramic-ceramic composites (e.g.,Si-SiC), metal-metal (e.g., Fe-Cu and stainless steelCu)materials are used. In the above metal-metal composite Cu is used for bonding the ferrous or steel in order to enhance mechanical properties. CoCrMo/Ti6Al4V, TiC/Ti, Ti/TiO2, Ti6Al4V/IN718 are some of the functionally graded composite materials used in AM processes [7].

Natural and Distinct Materials for AM Applications

Materials which occur in nature are termed as natural materials or naturally derived materials. These materials are applied to Additive manufacturing technologies, which are highly influencing the material world in all fields. Apart from these materials several diverse and distinct materials can be used for 3d printing here some of the materials are discussed which will give a brief idea towards where the technology is moving.

Laywood-D3 is a material founded by a company known as KAIPA in Germany which is a mixture of wood powder combined with polymer binders and available in the form of filaments with which 3d printing is possible. This material has very less applications but very good in aesthetics [19].

Figure 5. 3d printed wood artifact

Some of the studies explains that Sand, mud, clay, porcelain(China clay) may also be used as materials for 3D printing, WASP an Italian 3D printing company used mud as a material and printed a model of house. Another Dutch company Vormvrij developed a 3D printer which can utilize clay as a material for 3D printing [16]. DUS Architects at Amsterdam started printing a house with the Kamer Maker, or Room Builder by using hotmelt – an 80 per cent bio-based material which is 75 per cent plant oil.[19] Wax is one of the ancient naturally derived material which can be used for additive manufacturing, candellila wax powder mixed with carbon powder in 100:7 ratio can be treated as perfect blend for 3D printing.

Proteins and Vitamins can be 3D printed by a 3D printing technique called as two photon polymerization. Researchers from North Carolina State University, investigated on nontoxic polymers for medical implants derived from compounded riboflavin which is also known as vitamin B2. Living tissues derived from human and animal bodies can be converted in to “BIO INK” which can be can be used to print 3D tissue constructs like internal organs with a predefined pattern. So far blood vessels, bladders and kidney parts have been 3D printed.

Figure 6. 3d printing of ear cartilage tissue

Sea urchin shells powder can be utilized to extract calcium phosphate which is one of the porous ceramic material can be used for printing of artificial bones. Normal bone powder combined with binders and material called Malto dextrin to print artificial bones [18]. Researchers at Barcelona’s IAAC (The Institute for Advanced Architecture of Catalonia) are working on a soybean based material that could be extruded and is equivalent to strength of concrete used in construction [15].

Plastic waste from oceans and shorelines in Alaska is recycled and extruded in to plastic filaments for application in 3D printing. Chocolate powders and pastes can be applied in 3Dprinting to produce Chocolates of different complex structures. Chocolate printers use the computer-aided-manufacturing systems to set up the designs and then print. Similarly pastries and pizzas can also be 3Dprinted.

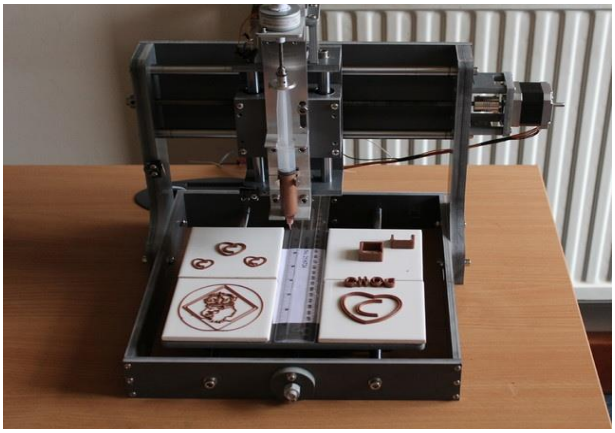

Figure 7. 3d printer using chocolate pastes as a material for printing

Not only materials are derived from nature some of the techniques and orientations are also copied from nature for example researchers at MIT(Massachusetts institute of technology) done experiments to create a robotic controlled extruder which deposits the natural fibers just like Bombyx mori silk worm constructs the cocoon. Researchers from the same institute working to produce 3D printed body armor which is a biomimentic of scales on the body of dragon fish [20].

Conclusion

In this paper a detailed study of various materials for Additive manufacturing industry are presented and a overview of certain distinct materials applied in AM processes are discussed. AM processes are classified into four categories: liquid, filament/paste, powder, and solid sheet. Polymers which come under filament based category of materials have gained much attention due to its huge applications in the field of prototyping. In recent years a lot of attention has paid on metal powders due to its production capability of functional parts. However attempts have been made to directly fabricate ceramic components by AM, still intensive research is needed before commercialization. Composites seem to be not much highlighted in AM due to vast post processing operations. AM technology is showing great potential and advantages in industries like aerospace, automotive, tool making, bio-medical and consumer goods still it is treated as niche technology due to limited material resources so a lot of research and development has to be done on materials for AM technology to elevate it as a main stream technology.

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