Opportunities in 3D Printing for Nanocomposite Materials: A Review

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Abstract: Developing a product, layer by layer increases design and manufacturing flexibility, hence complex geometries, product customization and shorter time to market enabled. For that, additive Manufacturing is emerging as an enabling technology for a wide range of new applications. 3D printing is most popular process within additive manufacturing. In this process, it deposits materials layer-by-layer to build a product. It is considered as a third industrial revolution because it presents new and expanding technical, economical and social impacts. This review paper provides a basic understanding of 3D printing processes, different materials used and about effective printing parameters.

Keywords – Additive Manufacturing, Nanocomposites, Carbon Nano Tubes (CNT).

I. INTRODUCTION

3D printing is a process of making objects by depositing material layers directly. The layers are generated in variety of ways depending on the technique. This technology allows complex product design and also avoiding assembly process. 3D printing being a tool-less process, significantly reduces the prohibitive costs and lead times. Charles (Chuck) Hull of 3D Systems developed the first working 3D printer in 1984.[1] While 3D printing has been around for almost 30 years, it is still a nascent market with low market share concentration although rapid growth is expected. Additive manufacturing (AM) is a technique for fabricating parts in precise geometry using computer aided design (CAD) and computer aided manufacturing (CAM). The 3D model designed in CAD software is converted to STL format, which is a triangular mesh of the object, and then the STL format is sliced into 2D profile layers. Each sliced layer of the model is bonded to the previous layer on the build platform until a 3D part is fabricated.

Nanocomposite: From last few years, there has been a drastic development of nanocomposites, where at least one of the dimensions of the filler material is of the order of a nanometer. The final product does not have to be in nanoscale, but can be micro- or macroscopic in size. [2] Polymers are commonly mixed with a variety of both synthetic and natural compounds to improve their performance capabilities. So that potential chemical, physical and mechanical property enhancements that can be achieved in nanoparticle/polymer. [3, 4]

Fig.1 Stages of 3D printing Technique

II. METHODS OF 3D PRINTING

Mainly the 3D Printing technology classifies as below and overview of Bulk solid-based technologies

- Laminated object manufacturing (LOM)
- Fused deposition modelling (FDM)

Powder-based technologies

- Three-dimensional printing (3DP)
- Selective laser sintering (SLS)
- Selective laser melting (SLM)

Slurry-based technologies

- Stereolithography (SLA)
- Digital light processing (DLP)
- Two-photon polymerisation (TPP)
- Inkjet printing (IJP)
- Direct ink writing (DIW)
Fused Deposition Modelling (FDM)
FDM is the most commonly used for fabricating polymer composites, like PC, ABS and PLA, are commonly used due to their low melting temperature. In FDM, filaments melt by extruder nozzle and spread layer by layer onto the build platform where layers are fused and then solidify into predefined design.[2] Quality of output can be controlled by altering printing parameters like thickness of layer, orientation of object, speed, temperature, layerheight.[20] In FDM, raw materials must be in a filament form. FDM is widely used because of its advantages like cost, high speed and simplicity, also we can use multiple extrusion nozzles with input of different materials.

![Fig.2 Schematic illustration of FDM Technology][20]

Powder based and inkjet 3D printing (3DP)
The inkjet printing is based on the 2D printer technique in which jet is used to deposit tiny drops of ink onto paper & Powder form material is used in powder bed method. Liquid drops of materials instantly cool and solidify to form a layer. Free powder is removed from the platform by vacuum.

![Fig.3 Schematic illustration of Powder and inkjet technology](image)

Stereolithography (SLA)
Being a laser based process; it uses ultraviolet laser and a vat of resin to build parts. The laser beam marks the design onto the surface of the liquid polymer.[7]
Selective Laser Sintering (SLS)
SLS technique is developed by Carl Deckard and Joseph Beaman at the University of Texas-Austin in the mid-1980s.[9]. SLS is another powder-based 3D model fabrication method. Main advantage is that a wide range of materials from polymers to metal and ceramic powders can be used in SLS technique.[11]

3D plotting/direct-write
In this technique ink-deposition nozzle is there which controlled architecture and composition of material.[4] Colloidal gels are excellent candidate materials for direct ink writing of complex 3D structures, because their viscoelastic properties can be tailored over many orders of magnitude to facilitate flow through nozzles and produce patterned filaments that maintain their shape, even as they span gaps in the underlying layers of the printed structure. [5,6,]

PolyJet
Poly jet process is similar type of process to the ink jet printing. Instead of jetting drops of ink onto paper, the printer jets layers of liquid polymer onto a tray and then the UV rays instantly cure the model.[20,23]

Digital Light Processing (DLP)
Working principle of DLP is a similar as Stereolithography. DLP uses conventional light sources to curing the photo sensitive polymer resin. which is based on selective polymerization of an entire surface of photopolymer by a projector light [16].
Fiber Encapsulation Additive Manufacturing (FEAM)
In FEAM a fiber and a matrix are co-deposited simultaneously within a single printer with straight and curved 2-D and 3-D paths. In this method the fiber is a metal wire and the matrix is a thermoplastic polymer, simple electromechanical devices such as voice coils, inductive sensors, and membrane switches have been successfully produced. [17,18]. That permits the printing of electromechanical and electronic devices within a single, affordable machine.

Laminated Object Manufacturing (LOM)
LOM developed by Helisys. It generates a 3D model by stacking layers of materials like paper, plastic, and metal.[10] After the first layer of material is loaded onto a platform, a laser traces the designed cross-section to define the pattern on the layer. After that excess material of the sheet is removed, the platform then rises slightly and the heated roller applies pressure to bond the a second layer, it covers the previous layer and the laser or knife tracing will define the next pattern based on available .STL file. [11, 15]

III. MATERIALS
3D Printing technology is applicable to all type of materials including metals, ceramics, polymers, it’s composites and nanocomposites.[27]

Polymer Materials:
Polymers become an important part of our regular life due to their unique characteristics such as ease of production, light weight and ductile nature.[49] Poly(lactic acid) (PLA) used with LDM technology.[45] Acrylonitrile butadiene styrene (ABS) and Polybutylene terephtha-late (PBT) is used with FDM technology and proved for Sufficient mechanical strength, stiffness, and chemical resistance for user specific application.[44,46] Polyurethane (TPU) used with SLS Technology for Flexible circuit, wearable devices, implantable devices, electronic skin, dielectric elastomer actuators.[47] Guo et al. processed PLA/MWCNT
Metal Materials:
Currently majority of the more than 5,500 alloys in use today cannot be additively manufactured because the melting and solidification state during the printing process, only a few alloys having low to moderate melting temperature can capable to perform, the most relevant being AlSi10Mg, TiAl6V4, CoCr and Inconel 718, can; the vast. High-quality metal powder must be requiring for quality powder bed fusion. A variety of stainless-steel metal powders are used. Excellent fusion characteristics make aluminium alloys particularly well-suited for use in 3D printing. 3D-printed parts fabricated from cobalt chrome alloys like ASTM F75 CoCr when excellent resistance to high temperatures, corrosion and wear is critical. Prof. Schroers et al. has focused on a bulk metallic glasses made from zirconium, titanium, copper, nickel and beryllium, with alloy formula: Zr44Ti11Cu10Ni10Be25 and same will be used in 3D Printing as it generate solid, high-strength metal components under ambient conditions. Silver nanoparticle based microelectrodes embedded between layers of hydrogel material were successfully fabricated. 3D bioprinting is employed to print the entire bioelectronics platform comprising of conducting silver ink and Gelatin methacryloyl (GelMA) hydrogel.

Ceramic Materials:
Along with extensive research on the three-dimensional (3D) printing of polymers and metals, 3D printing of ceramics is now the latest trend to come under the spotlight. The ability to fabricate ceramic components of arbitrarily complex shapes has been extremely challenging without 3D printing. Lewis et al. used concentrated HAP colloidal inks to create 3D periodic scaffolds through the DIW process.

IV. APPLICATION OF 3D PRINTING
- Medical Science (Orthopedic, dental, tissue engineering, Porous bone scaffolds) [30,31]
- Construction (building sections and structural panels)[32]
- Automotive (Spare parts & Prototype model)[34]
- Electrical and electronics (electrical components and printed circuit boards) [17,21]
- Automation Equipments (Sensors, Actuators)
- Aerospace (Flame retardant panels and high performance components) [35]

V. CONCLUSION:
The objective of this study was to gather the innovation and developments in technologies. 3D printing technology revolutionized and reshape the world as it is very exciting technology with huge potential also comprising the different technologies at one place, taking into account their economic benefits and social impact. A number of applications already exists, while many potentials are possible for these materials, which open new vistas for the future. 3D printing has revolutionized the way in which manufacturing is done. It improves the design manufacturing and reduces lead time and tooling cost for new products.

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