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Additive Manufacturing for Polymers and Polymeric Composites Comprehensive Review

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ABSTRACT

Additive Manufacturing (AM) is one of the flexible manufacturing techniques applied to polymers, composites, metallic powders, and their technologies are compatible with different materials, methods, and applications. (AM) has extended beyond simple prototyping and began to play role in fabrication of components for different applications and for highly complex geometries that are not easily attainable via subtractive manufacturing techniques. In the last few years, a tremendous growth in the (AM) applications has offered a plethora of applications, which are already being utilized in almost every sphere of life.

The exponential use of different materials, polymers, composites, and metallic powders – in different industrial sectors caused an increase in waste generation, which has increased by its turn the awareness for their environmental and economic impacts and drew the attention to the importance of having green (AM) technology and to the significance of having distributed recycling via (AM).

Key words: *Additive manufacturing, polymers, composites, economic impacts, waste generation.*

1. Introduction

Additive Manufacturing (AM) alias translates computer- aided design (CAD) virtual (3D) models into physical objects. By digital slicing of CAD, 3D scans, or tomography data, (AM) builds objects layer- by- layer without the need for molds or machining.

Recently (4D) printing offers the capability to from complex 3D structures that could adapt different predetermined forms and shapes when subjected to different environmental stimuli (1). Because polymers are by far the most utilized class of materials for (AM), many reviews were published on polymer processing and the development of polymers and advanced polymer systems specifically for (AM). It is worth to mention that the bibliometric analysis from Scopus database shows that 30,700 bibliographic articles published in the last decades (2000 – 2019) on (AM/3DP). Moreover, in the same period globally 157,132 patents were filed on (3D/AM). Global trends for the countries reveal a prominence of that, the U.S.A was the most prolific country regarding (3D) printing with 8705 publications, followed by China with 5603 publications. Similarly, the maximum number of patents in U.S.A is 86,708 patents, followed by Japan with 40,519 patents (2). According to Wohler's (3) the market for (AM) machines and the related products, services and software in the year 2020 was about 15.8 U.S dollars and is expected to be about 35.6 billion in the year 2024.

(AM), since its inception in the 1980s, has evolved and blossomed into a plethora of processes, and is now enabling "on-demand" manufacturing and drastically reducing inventories and wait times. According to the 2013 Wohler's Report (4), the compound annual growth rate of worldwide revenues of all (AM) products and services over the past twenty-five years was 25.4%.

It has been long recognized that (AM) may offer various environmental benefits, such as less material waste, energy efficiency, and transportation impact reduction by manufacturing locally or on site. (AM), is one of the leading industries among those supporting the 4th Industry in the whole world (5).

I. Shedding light on (AM) and its application for polymers

(AM) has emerged during the 1980s to serve the highly specialized needs of model making and rapid prototyping. (AM) served as versatile technology platform for computer aided design and digital manufacturing (DM). (A.M) allows the production of customized parts from polymers, metallic powders, ceramics, and composites without the need for molds or machining typical for conventional, formative, and subtractive fabrication. (3D) printers today are available for less than 500 US Dollars, enabling desktop fabrication of (3D) object even at home. In the same way, the development of digital (2D) printing together with desktop publishing has revolutionized communication and information technology (6). The development of (AM) technologies in conjunction with the "internet of things" has potential to revolutionize computer aided manufacturing (CAM) of both complex objects and multifunctional material systems (6). Whereas conventional fabrication is governed

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by process constraints related to industrial mass production. (AM) is inherently agile enabling factor turnaround on design and manufacturing of customized objects tailored to meet the demands of individuals and specific applications (7). The development of easy-to-easy systems exhibits sufficiently fast build speeds and a decrease in system pieces. (AM) has moved from the area of niche manufacturing processes into the spotlight of a much larger audience (8). Despite the great progress that has been achieved in recent years, there are still number of challenges that need to be tackled to establish (AM) as a manufacturing tool on large scale. Many of these challenges are related to the insufficient material properties (thermo-mechanical, anisotropy, porosity, longtime stability, cost, corrosion properties, creep…. etc.), of the currently used build materials (9).

Additive Manufacturing (AM) is not any more defined as a technology that builds three-dimensional (3D) objects through layer-by-layer addition of material known as (3D) printing. Thanks to chuck Hull who is suggested the application of (AM) technique in polymers in the early 1980s and patented his work (10, 11). Nowadays (AM) has extended beyond simple prototyping and began to play a role in the fabrication of active components especially for applications that do not require materials with robust mechanical properties such as electronic components and bio-medical scaffolds (6). (3D) printing is referred to as the technique of fabricating polymers and polymeric composite parts that have highly complex geometries via layer- by- layer technique until the final product was developed. The parts are manufactured by using (CAD) model and optimized operating parameters (12). Compared to traditional manufacturing methods for polymeric materials such as injection –molding, thermoforming, extrusion, casting as well as computer numerical control (CNC) milling. (AM) represents a fundamentally different approach whereby individual layers are deposited sequentially to build up a (3D) structure. (AM) allows the production of complex geometries that are not easily attainable via subtractive manufacturing techniques (13). (AM) is particularly advantageous for small patch size production and development activities, since tooling and long lead times are eliminated in the manufacturing process. This allows a closer link between the user and the manufacturing stage and opens the doors for customized printed parts, which take advantage of computer- aided- design and drafting (CADD). This has made (AM) competitive in areas where there is an inherent need for custom-made products or where volume low tailored parts are attractive to the customer (13). The steps involved in the (3D) printing process are illustrated in Fig (1).

One of the early applications of (3D) printed organic materials developed in the early 1990s was for the fabrication of pharmaceutical capsules comprised of a drug and polymer binder. Trenfield, et al coined the term "printer" to refer to (3D) printed tablets with a tailored dose, shape, size and release characteristics that could be produced on demand instead of the conventional large batch processes that have been used for the one-size tits-all approaches. In January 2015 a Precision Medicine Initiative was launched with a concept of implementing treatment strategies and prevention that take individual variability into account (14).

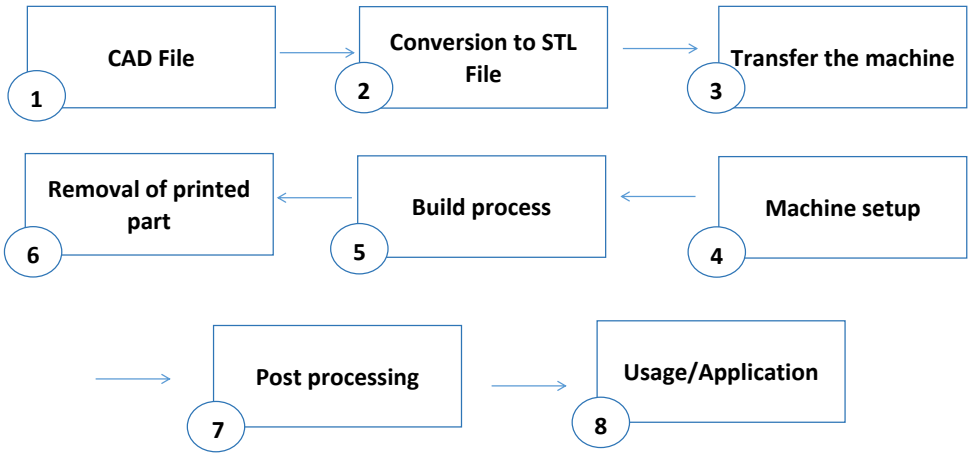

Fig1. Steps involved in the (3D) printing process

There are several printing methods for additive manufacturing of polymeric materials these methods are: Fused deposition molding (FDM), stereolithograply (SLA), Direct-write process, continuous liquid interface production process (CLIP) and selective laser sintering process (SLS). The (FDM) process is illustrated in Fig 2.

Yaragatti and Patnaik (15) claimed that (AM) has played a vital role in the supply chain of the medical equipment industries which faced mass shortages in the Covid-19 pandemic. The adoption of (AM) technologies in the world of manufacturing occurred in stages, which are identified as digital manufacturing, rapid tooling,

rapid typing and home fabrication (16). It is worth mention that the expiration of the original patens and the advances in the different (AM) technologies have made it possible to acquire a (3D) printer at accessible prices, as a result (AM) permits today both private and industrial users design to produce their goods (17). Today, a vast myriad of (AM) technologies has been developed depending on the type and form of material employed, deposition systems, source of energy used (heat, laser, or UV light) (18). ASTM implemented a classification for different (AM) technologies into seven different categories given in table (1): the different (AM) technologies are classified into seven categories as follows:

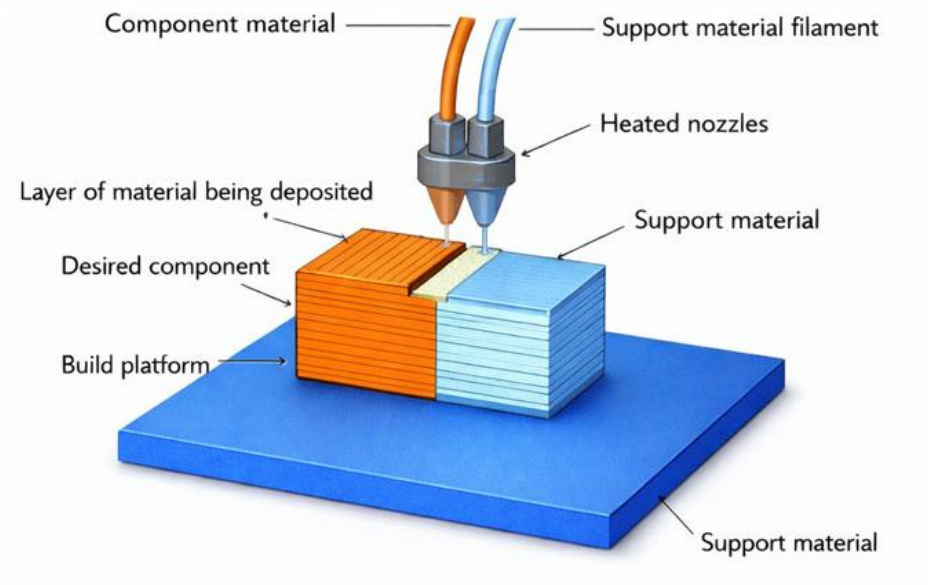

Fig. 2 Illustration of FDM process

Table (1): Additive manufacturing process types and attributes, including example companies, materials utilized in machines, and typical markets

Process	Example Companies	Materials	Market
Vat Photopolymerizatiom	3D Systems (US), Envisiontec (Germany)	Photopolymers	Prototyping
Material Jetting	Object (Israel), 3D Systems (US), Solidscape (US)	Polymers, Waxes	Prototyping, Casting Patterns
Binder Jetting	3D Systems (US), ExOne (US), Voxeljet (Germany)	Polymers, Metals, Foundry Sand	Prototyping, Casting Molds, Direct Part
Material Extrusion	Srratasys (US), Bits from Bytes, RepRap	Polymers	Prototyping
Powder Bed Fusion	EOS (Germany), #D Systems (US), Arcam (Sweden)	Polymers, Metals	Prototyping, Direct Part
Sheet Lamination	Fabrisonic (US), Mcor (Ireand)	Paper, Metals	Prototyping, Direct Part
Directed Energy Deposition	Optomec (US), POM (US)	Metals	Repair, Direct Part

i. Material extrusion, ii-powder bed fusion- iii- vat polymerization- iv- material jetting, v-binder jetting- vi-sheet lamination, and vii- directed energy deposition DED) (19).

ii. Another classification for (AM) based on the physicals state of the base material-solid liquid and powdered, and in which the medium used to process the base material- such as laser beam, UV rays, thermal means…. etc. This classification is given in Fig 3 (20). Various advanced materials and hydrogels have been used to improve the product quality and the bio capability of medical components.

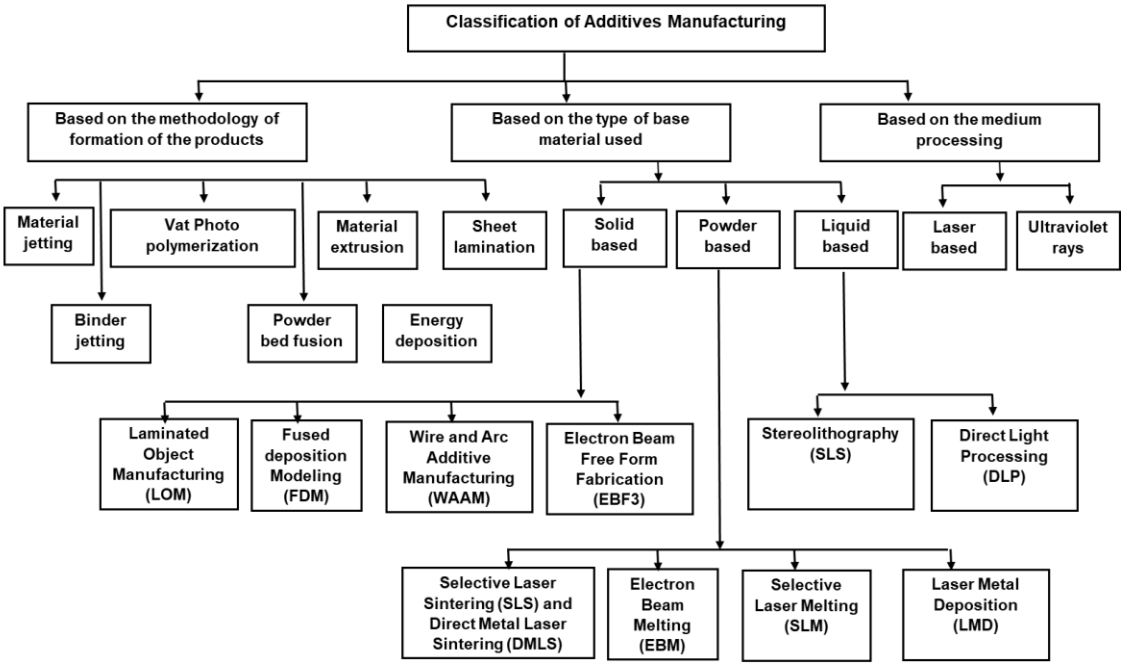

Fig. 3 Classification of additive manufacturing processes from different contexts

Each process has associated strength and weakness related to the following characteristics (21):

- The materials they can utilize (typically different polymers or metals, but also waxes and paper for some niche applications).
- The speed at which they can build parts (build speed).
- The dimensional accuracy and quality of the surface finish of the produced parts.
- The material properties of the produced parts.
- Machine and material cost.

In the year 2009, ASTM international committee (F 42) on (AM) technologies defined several terms to distinguish it from their competitors i.e. formative and subtractive … etc., and to classify different additive processes following the ASTM nomenclatures we get (22,23):

i. Material extrusion: is an active manufacturing in which the material is selectively dispensed through a nozzle-fused deposition modelling (FDM) and was used filament fabrication (FFF) (3D) dispensing, and (3D) bioplotting fall into this category.

ii. Material jetting: is an additive manufacturing process in which droplets of build material (such as photopolymer or thermos-plastic materials) are selectively deposited. System based on inkjet-printing fall into this category.

iii. Binder jetting: is an additive manufacturing process in which a liquid bonding agent is selectively deposited to fused powdered materials.

iv. Sheet lamination: is an additive manufacturing process in which sheets of material are bonded together to form an object.

v. Vat Photo-polymerization: is an additive manufacturing process in which a liquid photopolymer in a vat is selectively cured by light-activated polymerization. Many of the lithography-based (AM) processing (DLP) and stereo-lithography (SLA) can be grouped into this category.

vi. Powder bed fusion: is an additive manufacturing process in which thermal energy (provided e.g., by a laser or an electron beam) selectively fuses regions of a powder bed. Selective laser sintering (SLS) or electron beam machining (EBM) fall into this category.

Table 2 lists the categorized (AM) techniques for polymers, giving the more pertinent features and their limitations (24).

Table (2): Categorized AM Techniques for Polymers along with Advantages and Disadvantages

Categorized Techniques	Typical and Largest Build Volume	Typical Feature Resolution	Typical Materials	Advantages	Disadvantages
Vat Photo polymerization exposure from top	250 X 250 X 250 mm^3 800 X 330 X 400 mm^3 (Prod ways)	50 – 100 μm	Acrylates/epoxides	Excellent surface quality and precision	Limited mechanical properties
CLIP exposure from bottom	150 X 80 X 300 mm^3 100 X 100 X 100 mm^3 300 X 300 X 300 mm^3 (Digital Wax 30X)	75 μm 25 – 100 μm	Acrylates Acrylates/epoxides	High build speed low initial vat volume; better surface quality	Low-viscosity resins required limited mechanical properties
Multiphoton lithography	5 X 5 X 1 mm^3 100 X 100 X 3 mm^3 (Nanoscribe)	0.1 – 5 μm	Acrylates	Very high resolution	Low build speed; limited materials
Powder bed fusion polymer SLS	250 X 250 X 250 mm^3 1400 X 1400 X 500 mm^3 (Huake 3D HKSI 400)	50 – 100 μm	PA12, PEEK	Best mechanical properties; less anisotropy	Rough surfaces; poor reusability of unsintered powder
Material and Binder Jetting Polyjet	300 X 200 X 150 mm^3 1000 X 800 X 500 mm^3 (Objet 1000)	25 μm	Acrylates	Fast; allows multimaterial AM	Low viscosity ink required
Aerosol jet printing	200 X 300 X 200 mm^3 (Aerosol Jet 5X)	10 μm	Conductive inks/dielectrics	High resolution; low tem process	Low viscosity ink required
3D printing (binder jetting)	200 X 250 X 200 mm^3 1000 X 600 X 500 mm^3 (Voxeljet)	100 μm	Starch, PLA, ceramics	Fast; allows multimaterial AM; low temp	Limited strength of parts; rough surfaces
Sheet Lamination laminated object manufacturing	170 X 220 X 145 mm^3 (Sol dimension SD 300))	200 - 300 μm	PVC paper	Compact desktop 3D printer	Limited materials; low resolution; high anisotropy
Material Extrusion FDM	200 X 200 X 200 mm^3 1005 X 1005 X 1005 mm^3 (BigRep One)	100 - 150 μm	ASB,PLA, PC, HIPS	Inexpensive machines and materials	Rough surfaces, high temperature process
3D dispensing	150 X 150 X 140 mm^3 (3D Bioplotter)	100 μm to 1 cm	Thermo-plastics, composites, photoresins, hydrogels, biomaterials	Broad range of materials	Rough surfaces; narrow viscosity process window

III- Application of Additive Manufacturing for composites

Additive manufacturing (AM) referred as (3D) printing has extended beyond simple prototyping and is being used for the fabrication of fully functional components in one of the flexible manufacturing techniques that can apply to polymers, metals, ceramics, and composites, and is based on the ability to select from a wide range of processable polymers and the enhancement in the properties offered by polymers (25, 26).

The increase in demand and high produced diversification range with reduced unit quantities led to the innovation of flexible and digitized production (27). The emerging concept like additive manufacturing (AM) is extensively used to make a prototype with insufficient mechanical strength. Thus, the (AM) industry has become predominantly targeting the production of polymeric composites. For addressing this problem, advancement in the production of fiber reinforced plastic (FRP) composites was introduced in additive manufacturing. The significant challenges in this area are the exact fiber placement, sizing of fiber, and their reality into engineering problems through effective control of the process parameters (28, 29). The growing demand for the prototype and tailored properties of (FRP) components obviously leads to new innovations intending to acquire short production cycle time and low cost in the manufacturing processes (30,31,32).

1. Sakhi, et al (33) considered that natural fibers could be a credible substitute for synthetic fibers because of their advantages like biodegradability and echo-friendly behavior, lesser density compared to synthetic fiber composites. However, the major reason for their limited potential in finding wider application is their hydrophilic nature because of its high content of cellulose and hemicellulose and due to its poor flame retardancy.

David Rejesk (34) based on the 2014 National Science Foundation (NSF) workshop on environmental implications of (AM) approved the key issues including energy use, occupational health, waste, lifecycle impact and crosscutting together with the policy issues in terms of their current state-of-art, research needs and recommendations respectively.

Parikh, et al (35) found that the results of the flexural strength revealed that wood particles made the material more porous and affects the interfacial adhesion between particles and matrix, and thus reduces the strength of the composite material. Ravinder Tonk (36) investigated the use of natural fibers obtained from animal and vegetable sources in additive manufacturing of parts for different applications, such as civil engineering, structural engineering and biomedical engineering applications. Sohib, et al (37) have concluded that the main impediments of using natural fibers are thermal stability, compatibility issues and moderate interfacial interaction. They have investigated the potential of cellulosic fiber based polymeric composites for automotive industries. R. Taurino (38) gave a clear overview on the recent development of waste valorization strategies in polymeric materials for the sustainable production of new polymer matrix composite.

2. Jolie, F, et al (39) in their investigation, concluded that the automated techniques play a key role in polymer composites manufacturing in number of industries. Anni, et al (40) found that thermal spray processes have been widely used for coating structures and applying thermal spray coatings onto (FRP) constituents has led to a broadening of application areas for ((FRP) materials and enhanced the performance and surface protection.

The accumulated waste after using carbon fiber reinforced polymer (CFRP) is pressing for its recycling, and thus a novel recycling approach, which is integrated to carbon fiber reclamation and composite additive manufacturing, was proposed by Hailong, et al to reuse the (CFRP) waste into three dimensional (3D) parts. In the experiments, the (CFRP) waste was recycled by supercritical n-butanol to yield reclaimed carbon fiber (rCF) (41). Sania Adil, et al delivered a comprehensive review for additive manufacturing for reinforced polymers (CFRPs). The review presents an insight into different additive manufacturing techniques with an overview of commercially available methods for manufacturing short and continuous fibers (CFRP) (42). Amine Marzoden, et al, published a review article on the experiments and developments associated with (AM) of (PMC) materials from 2018 to 2023 and provided a detailed discussion of current findings, challenges, and gaps (43)

Divya Zindani, et al presented an overview on the use of (AM) in fiber-reinforced polymeric composite materials. The scope of the review delineated different additive manufacturing processes, formulation of different materials, drawbacks, and strengths associated with different additive manufacturing processes (44). Alvaro Diaz-Garcia, et al (45) investigated thermal and rheological properties of polymer-based magnetic composite filaments; they introduced some commercial and tested composite filaments for functional applications of limited varieties and compositions.

In many cases, custom made composite filaments have to be manufactured to suite specific requirements, this implies an additional step for characterizing the prepared filaments as different additives can

affect the properties of the polymer matrix in a very different ways. On the other hand, mechanical properties and thermal behavior of composites could be improved with respect to the pure polymer, with some types of reinforcement fillers, such as glass or carbon fibers (46), plasticizers (47), or polymer blends (48). Regarding magnetic composites filaments, which has be used in numerus applications, the commercial stock is practically limited to polylactic acid (PLA) filled with 40 wt. percentage of iron particles (49). In recent work, Proto-Pasta has been used due to its soft magnetic characteristics, though the characteristics of the fillers are not ideal for functional applications as the iron particles are with consistent sizes and shapes, as well as easily rustable (50).

3. The innovative applications of (AM) have also opened newer challenges and avenues; one of such avenues is (AM) materials. Ruslan Melentieve, et al (51) suggested polymer metallization to face the intrinsic deficiencies exhibited in the surface of the polymeric materials and composites. This was widely used for designing structures in aerospace, automotive, electronics, sport industries due to their lightweight, cost, and processing advantages. The polymer metallization methods are physical vapor deposition, electrochemical plating, thermal spray methods and series of polymer metal direct bonding and fusion joining techniques, including ultrasonic joining, friction spot joining, electromagnetic induction joining, and laser joining. Meanwhile, Garcia, et al (52) suggested the addition of material, usually layer-by-layer to manufacture multifunctional products, (MMAM), which has a wide range of applications such as fabric, large format equipment, drones automotive, electronics and or droplet deposition. It should be noted that every (AM) process is compatible with different materials, methods, and applications, thus printing of fuel cells, art design, and manufacturing of light components, complicated and customized products may be manufactured without the requirement of expensive manufacturing methods. (AM) has adequacy in the working environment with a limited (3D) area. Usually, the industrial printers use area of 1 m^2, whereas newly developed machines are capable of (3D) printing with an area of 26 m^2. K. M, Pin (53) summarized the most significant benefits of (AM) as follows:

- Manufacturing of parts without tooling.
- Generation of intricate internal features with functional design.
- Lightweight and flexible components having hollowed structures can be easily manufactured.
- Design to component transformation.
- Functional parts manufacturing.
- Products without additional processing.
- Waste minimization.
- Time reduction.
- Environment-friendly.
- Easy scalability.

4. Narinder Singh and Germander Singh, in 2021 published a review on advances in polymers for bio-additive manufacturing. In this review, they included all basic and essential processes along with the used materials for biomedical applications, and emerging flexible materials such as metal polymer composites (54). In the year, 2021 Alireza et.al published a review article on additive manufacturing of metallic and polymeric load-bearing biomaterials using powder bed fusion. They concluded that among different (AM) methods laser powder bed fusion (L-PBF) is emerging as the most popular and reliable method for producing load-bearing biomaterials (55). Sundarakanaan, et al in 2023 reviewed metal and polymer-based manufacturing using additive manufacturing. They examined the mechanical performance of Metal and polymer-based composites using additive manufacturing (AM) techniques. Comparing (AM) based manufacturing processes to traditional methods reveals significant variations in the performance of the resulting composites. Further, on, this review delves into intricate details of metal and polymer based. Composites, shedding light on their mechanical performance and exploring the various industries and sectors, where they find utility (56). Electrically conductive polymer composites have sparked considerable interest community due to their unique advantages that come from combining regular polymers with the electronic properties of metals or semiconductors in a synergistic manner. Yinjia Yan et.al had in 2023 presented an insight into current research advances in the field of conductive polymer composites developed for additive manufacturing, which accelerate the design and development of (3D) printable electrical devices. They examined various (AM) processes in terms of their respective limitations, address the material requirements and significant breakthrough in (3D) printing of conductive polymer composites, and discussed their promising electronic applications, such as flexible electronics, energy storage and conversion devices (57). Sanjiev Mahato, et al in 2023 reviewed the material selection considerations for (3D) printing of electrically conductive composites, as an emerging filed with broad applications in electronics, sensors, and energy storage, with an emphasis on the capabilities of the polymer, when combined with various types of electrically conductive filler materials (58).

Atish Kumar and Narendra Kumar, in 2023 gave a summary for the advances in the manufacture, characterization, and application of the electrically conductive transparent polymer composites (ECTPC). They discussed the various conductive filler material used in the ($ECTPC_S$) including metal powder, carbon nano-tubes (CNT_S) and graphene alongside their incorporation methods into the transparent polymer matrix (59).

In 2023, Merve Uyan and Melih Soner Celiktas evaluated the utilization of bio-based materials in shape memory polymer composites (60). Shape memory polymers (SMP_s) are part of the smart materials family. They can recover their permanent shape, from a temporary shape, upon application at a stimulus, such as heat, PH, etc. They are utilized in various multifunctional engineering design applications including biomedical, aerospace, and military fields, and therefore they are becoming increasingly important. Some of these applications require high mechanical and shape memory properties that cannot be offered with (SMP), therefore, the use of shape memory polymer composites ($SMPC_s$) has become a common practice. However, most (SMPs) and (SMPCs) are of fossil origin, and thus their extensive use raises environmental concerns. Consequently, in recent years, scientists and engineers started to investigate bio-based shape memory polymer composites (61, 62).

5- Properties of composite materials (63)

Two phases ever have identical properties since each will have a different structure. This generalization also applies to the properties of multiphase materials. Certain of these properties are additive and may be determined by suitably weighted averages o the properties of each of the individual phases. Other properties are interactive, because the behavior of each phase depends on the nature of the adjacent phase.

5.1- Additive properties (Mixture Rule)

The density of a multiphase composite may be calculated directly from the densities of each phase (ρ) and their corresponding volume fractions (f) as is given in equation (1)

$$\rho_c = \rho_1 f_1 + \rho_2 f_2 \qquad (1)$$

Fig. 4 shows that the density of a composite having only two phases, ρ_c varies linearly with the volume fractions (f) of the phases.

The specific heat of the composites has a similar additive relationship, which is also proportional to the volume fractions.

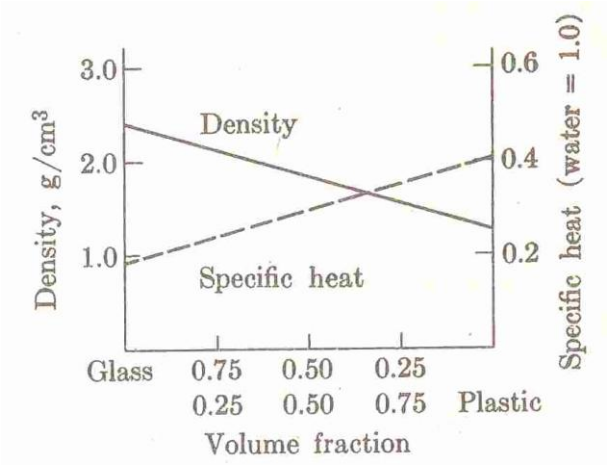

Fig. 4 The density and specific heat of a composite having only two phases

The thermal and electrical conductivities of multiphase composites are also additive; however, a more complex weighing procedure is necessary because the shape and distribution of each phase is important.

5.2- Interactive properties

On the other hand, properties such as hardness and strength cannot be approximated by the simple mixture rule. This is because of the interdependence of the phases and is referred to as interactive properties. This makes it possible to strengthen composites by the addition of fillers, or reinforced by fibers. The addition of wood flour e.g., to a phenol-formaldehyde resin as illustrated in Fig 5. The phenol-formaldehyde resin has considerable strength alone, it is subjected to eventual shear failure under stress, but the incorporation of a second phase produces added resistance to deformation at the other end of the composition range. The strength

of wood flour (fine sawdust) is nil, there are no forces that hold the individual particles of cellulose into the coherent mass. The addition of the resin to the fine particles serves to cement the wood flour particles together. The maximum strength is developed with intermediate compositions; with the two phases strengthen each other.

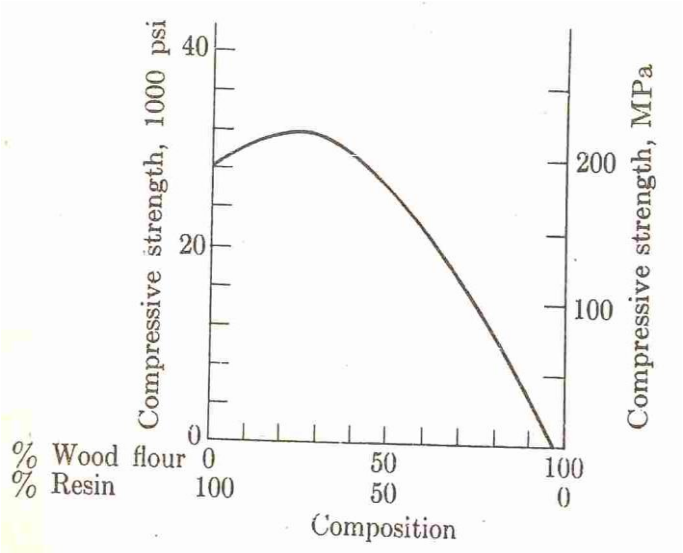

Fig 5 Addition of wood flour to a phenol-formaldehyde resin

6- Conclusions

Additive manufacturing (AM) is not any more considered a (3D) printing technique. The use of (AM) allows the easy and direct conversion of (3D) image into a final product without tooling i.e., without any additional cost involved in the manufacturing process. The produced components via (AM) can be easily customized to meet the customer demands.

Although (AM) is applicable to polymers, composites and metallic powders, polymers are by far the most utilized class of materials for (AM).

Significant advancements in (AM) of polymeric materials have been made over the past two decades with printable polymers finding new applications in medicine, electronics, and high-performance structural materials.

Conflicts of Interest

The authors declare no conflicts of interest

References

1. Samuel, C. L., et al, Chemical Reviews (2012) P. 10212, July 32, 2017.
2. S. Riaz, K. Y. Rhee, S. J. Park, Polymers 2021, 13 (2), 253.
3. Wohlers Report 2017, Annual Worldwide Progress, FORT COLLINS, co, 2017.
4. Wohlers Associates: Fort Collins, Co, 2015.
5. Jayanth, S., et al, International Research Journal of Engineering and Technology (IRJET), V. 108 Issue 07, July 2021.
6. Hull, C.W, US. Patent US 4575330A, 16 February 1984.
7. Chemical Reviews (2017), p. 10213.
8. Hayden T., et al, SANDIA Report April 2016- 6644.
9. David Rejeski, et al, Elsevier (2017), available online.
10. Hull, C.W (UVP, Inc) US. Patent 4575330, 1986.
11. Hull, C.W., et al, US Patent, 1998.
12. A. Garcia-Collado, et al, Additive Manufacturing. 50 (2022) 102577.
13. Saad, S.A., et al, Poymers 2021, 13, 753.
14. Trenfield, Materials Today, 2019.
15. N. Yaragatti, et al, Material today proceeding, 44 (2021) pp 4150-4157.
16. Chemical Reviews, (2017), pp 10267-10268.
17. Justin project leader, IDA, Science and Technology Policy Inst., March 2012.

18. Archimede, et al. Proceeding CIRP 112 (2022) pp 448 – 453.
19. Gibson, et al, Springer, New York. NY. 20152 pp (45-268).
20. Mauricio, A., et al, Polymers, 2022, 14, 1341.
21. Lozo, B., et al, J. Image Sci-Technology, 2008, 52, 5 (1004-8).
22. ASTM, International Worldwide, http://www.astm.org (accessed Mar 25, 2014).
23. ASTM, F2792-12a. Standard Terminology for (AM); ASTM international; West Conshocken, PH, 2012.
24. Manu Srivastava, et al, J mr & T, 2022, 2641.
25. J.M. Jefferson, et al, Material Today proc. 46 (2021) pp (1349-1365).
26. Chemical Reviews, 2017 pp 10256-10262.
27. U. Kalsoom, et.al, RSC Adv., 6 (44) (2016) pp (38140-38147).
28. Yang. H., et al, MRS, online Proc. Libr, 2011, 1312, pp (04-07).
29. Hegge. W., et al, Dig. Tech. Pap-Soc. Inf. Disp. Int. Symp, 2011,42, pp (837-840).
30. Polanikumar K, et al, Elsevier, Current Opinion in Chemical Engy. 2020-18:51-59 available online.
31. Rohit Pandy, et al, Material Today: Proceedings, 60 (2022) pp (1565-1569).
32. Janet Wong, et al, Composite Part B, 255(2023) 110603- Elsevier.
33. Sakshi et al, Material Today proc. 50 (2022) pp (1417-1424).
34. D. Rejeski, et al, Additive manufacturing, 19 (2018) pp (21-28).
35. Hiral, H. Parikh, et al, Materials Today: Proc. (2023)
36. Ravinder Tonk, Materials Today, Proc. 37 (2021), pp (3087-3090).
37. Sohib, dua, et al, Jmr & T, 2023; pp(1036-1104) available on line.
38. R. Tourino, et al, Materials Today, 21 (2023) 100298.
39. Jolie Frketic, et al. Additive manufacturing, 14 (2017) pp (69-86).
40. Ibnaj Anamika Anni, et al, Materials Today Com. 35 (2023) 105650.
41. Haihong Huang et al, CIRP Annals Manufacturing Tech. 69 (2020), pp (33-36).
42. Samia Adil, et al, Applied Polymer Sci. 2023; 140 and 2022 Wiley Periodicals LLC.
43. Amin Memarzadeh, et al, Materials Today Com. 36 (2023) 106449.
44. Divya Zindani, Intern. J. of Lightweight Materials and Manufacture 2 (2019) pp (267-278).
45. A.D.Garcia, et al, Materials and Design, 219 (2022), 110806.
46. T.D. Ngo, et al, Composites, Part B, Eng. 143 (2018) pp (172-196).
47. J. M. Chacon, et al, composite Sci. Technol. 181 (2019)
48. A.S, Deleon, Mater. Des. 182 (2019).
49. E. Castro- Aguirre, Polymer Degrad. Stab. 154 (2018) pp (46-54).
50. P. Zhao et al, j. Clean Prod. 197 (2018) pp (1046-1055).
51. Ruslan Melentiev, et al, Materials & Design, 221 (2022), 110958.
52. A.D. Garcia, et al, Mater. Today, Commun. 24, 2020, 101049.
53. Mahato V.k., et al, maderials Today Proceedings 2023.
54. Narinder Singh, et al, Journal of Manufacturing Processes, 72 (2021) pp (439-453).
55. Alireza, et al, J of Materials Science & Technology. 2021, published by Elsevier on Behalf of Chinese Society of Metals.
56. Sundarakannan, et al, Polymers 2023, 15, 2564.
57. Yinjia Yan ,et al, Materials Today advances, 17, (2023100333.).
58. Sanjeev K.M., et al, Materials Today: Proceedings (2023). 07.185.
59. Atish Kumal, et al, Materials Today: Proceedings (2023). 07.211.
60. Merve Ugan, et al, European Polymer J., 195 (2023) 112196.
61. Polymers 2022, 14, 1351.
62. Polymers, 2021, 13, 753.
63. M. H. Ashby, Material Selection in Mechanical Design, Pergamon Press, 1992.