A review on Manufacturing, Machining, and recycling of 3D printed composite materials.

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Abstract. This paper includes a comprehensive review of the literature on the latest research and development in 3D printed composite materials and its behavior with several machining processes. Machining parameters need to be considered while performing an operation like drilling, turning, shaping, and surface finishing on 3D printed composite material for providing some useful new application with excellent benefits. Also, recycling of plastic waste which is the most challenging hurdle of society nowadays is discussed, and the scope of its real-life implementation is observed.

Keywords: Additive manufacturing, Machining of composites, recycling of plastic waste.

1. Introduction

It’s a very well known that composite provides superior strength to weight ratio, excellent fatigue, and corrosion resistance. Apart from all these qualities, composite material provides long life durability and light weight structure [1]. A composite is considered as a structural material in which 2 or more than 2 materials that are united at a macroscopic level. Any one constituent is reinforcing phase, and the second is matrix phase. Reinforcing material may be in form of small scrappy, flakes or fibers and the matrix phase constituents are generally uniform [2].

Additive manufacturing has become ordinary for the moulding parts and objects for uneven geometries and structures. Latest innovations that validate formation of composite materials shows that the additive manufacturing technology or commonly known as 3D printing can offer a much broad design space besides unusual forming [3].

3D printing or additive manufacturing is emerging as an enabling technology in recent years for a wide range of applications. It can be stated as the “joining process for materials to manufacture parts or model from 3D modeling data, by applying layer upon layer, as opposed to subtractive and formative manufacturing technologies” Additive manufacturing is versatile regarding materials. The versatility of 3D printing material comes from the huge system variety, For all application printing materials are still having shortage and further research and development of materials still in progress. There are two main challenges in additive manufacturing technologies: (1) Improvement in resolution
and velocity of the printing process with lower power consumption. (2) It requires developing new printing materials with more effective physical, chemical and mechanical properties [4].

Carbon fiber reinforced polymers/plastics (CFRP) offers excellent mechanical strength. Post machining of CFRP is a mandatory step that assures that the fabricated parts form their measurements, shape and size and also meet their surface quality tolerances along with other functional requirements. Also the machining of CFRPs now a day’s considered an very difficult process due to the non-homogeneous structure, abrasive nature and highly nonlinear. Processes in CFRP machining, unconventional hybrid processes, and conventional processes, were invented based on the requirements of market [5].

2. Additive Manufacturing (AM)

3D printing technique or Additive manufacturing that takes the digital data from a CAD file that is later converted to STL file and produce a model, sculpture or parts as shown in figure 1. 3D printing is easier for architects, automobiles, mechanical components, and many more applications. Still, the precision requires improvement to reduce the requisite of a finishing process and to become able to manufacture models that demands the high level of accuracy [6]. From the dependency on the material, many problems occur during the manufacturing process, and the manufactured part gives many varieties in mechanical properties. By experimenting on research for reproducing textile structures, it is found that textile-based structures are 3D printed using SLS (selective laser sintering) and FDM (fused deposition modeling method), While Acrylonitrile butadiene styrene (ABS) material has turned out to be often brittle for the desired structures [7].

![Figure 1. 3D printing technology](image)

Additive manufacturing application is limited by printing materials available. Currently, thermoplastic polymer, materials formed in powder and photopolymers are possible to use in 3D printing. Moreover, this limitation could not fulfill the requirement of additive manufactured parts with huge verities in industries [8]. 3D printing is technology which is rapidly expanding in industrial sectors. However, it’s growth is still hampered by lower mechanical properties, low productivity, poor quality and uncertainty of final product. The most commonly modeled additive manufacturing process is SLA, followed by FDM and SLS/SLM (selective laser melting) [9].

The ability to produce complete microfluidic parts or model from a CAD model has an obvious attraction. Current states for 3D printing of microfluidics, specifically focus on four widely used 3D printing methods are Inkjet, FDM, 2PP, and SLA. Fused deposition modeling printer allows for the use of a wide range of thermopolymers and gives material compatibility with mass production. The resolution of rough channel surfaces that can be obtained in FDM is 100 µm. In the future fabrication of micro channels needs to be lowered to 10 µm, in a range of different materials with variation in physical and chemical properties [10]. FDM is limited by the particular operational materials for respective application. Printing of non-conventional polymer Carbon nanotubes (CNT) and graphene...
based polybutylene terephthalate (PBT) nanocomposites on a currently available 3D printer are illustrated by K. Gnanasekaran et. Al, and evaluation is done for conductivity of electricity, printability of material and stability in structure at microlevel of the composites before & after additive manufacturing. 3D printed parts with PBT/CNT gives higher mechanical properties, and electrical conductivity and overall better performance compared to PBT/graphene models fabricated by 3D printing technology. Additionally to printing of multi-materials, problems faced in abrasive fillers are also discussed. The most favorable printing conditions are not changing for the PBT/G and PBT/CNT [11].

3. Manufacturing of composite parts using 3D printing technology

Recent additive manufacturing process presents the capacity to create a fine shaped structure with difficult shapes and size, thus eliminating the need for joints/fasteners and multi-step processing. AM provides unique chance for the manufacture of multi-directional performs [12]. Fused deposition modeling additive manufacturing technique is used to manufacture continuous carbon, glass and Kevlar fiber reinforced composites in Markforged Mark One 3D printer. The investigation made on the influence of volume fraction, fiber orientation and fiber type; tensile strength values ware up to 6.3 times that obtained with the non-reinforced polymer [13].

The AM technique known as 3-dimensional printing technology has attracted much more attention in industry and academics in recent years [14]. Poly lactic acid (PLA) and Carbon fiber filament were used as matrix phase and reinforcing phase respectively, and supply into the FDM (fused deposition modeling) 3D printing process for manufacturing and forming CFRTPCs (Continuous Fiber Reinforced Thermoplastic Composites) [15]. The development of design to get benefit of the possibilities given by additive manufacturing and to eliminate the constraints connected with the technology has lagged [16]. AM holds tremendous promise regarding revolutionizing latest manufacturing processes, but the fundamental hurdles limit the use of this technology like lower production rate, physical size, poor mechanical properties [17].

For manufacturing continuous carbon fiber thermosetting composite 3D printing process was created to design and fabricate the composites on FDM. A 3D printed thermosetting composite material gives the superior mechanical performance compare to 3D printed thermoplastic composites [18]. Thermo-mechanical properties of new materials can be observed by manufacturing new polymer composite filament. The acrylonitrile butadiene styrene (ABS) thermoplastic was mixed with iron and copper particles in various proportions to find the effect of metal particles on various mechanical properties. It was observed that tensile strength decreased by increasing metal percentage and thermal conductivity increased by increasing the metal particles percentage [19].

Bio-inspired composite materials were manufactured by computationally designed 3D printing technology with predicted fracture response and compared to synthetic composites with having similar mechanical properties. The results point out that CAD models can be used to create new materials for printing to reveal fracture properties [20]. FDM technology has become one of the most used rapid prototyping methods because it offers the opportunity to design and manufacture new materials [21].

Additive manufacturing technology is now repeatedly spreads in many fields of research and development. A comparatively narrow range if 3D printing materials with a limited spectrum of physical, chemical and mechanical properties still constrain the competence of this undisciplined additive manufacturing technology [22].
4. Machining of 3D printed composite parts

Mechanical machining has been repetitively used for the fabrication of hybrid CFRP (carbon fiber reinforced polymer) stacks in order to ensure suitable applications. Due to inhomogeneous and poor machinability, CFRP machining has bought difficult challenges to the latest designing and fabrication industries. Drilling experiment of CFRP/Ti stacks were executed on a 5-axis CNC (Computerized Numerical Control) machining center in dry cutting condition. The interface machining is usually most challenging cutting stage in drilling due to multi-too-work interaction existence, in which undesirable transformation of physical/mechanical reactions dominate and chip formation modes coupled [23]. Aerospace composite and alloys need high-performance cutting performance. Research in tool development and its impression on surface integrity characteristics & tool wear were studied for titanium, nickel-based alloys, and composites. Recent machining problems have now come out with the research of even more latest aerospace alloys and composites [24].

The combination of glass and carbon fibers in composite materials creates the machining of these excellent materials challenging. Machining of CFRP/GFRP (Glass fibre reinforced plastic) material gives poor hole qualities, experiments shows that CVD diamond coating cannot achieve any advantages [25]. Turning is a 3D process through the primary and secondary cutting edges of part; it can be make process easier into an orthogonal cutting. The emerging and advanced field of multi-scale 3D printing is playing a principle part in the machining for composite laminates. Powder metallurgy were used to manufacture Metal matrix composites, and the effect of milling characteristics on cutting force and surface roughness with the use of uncoated carbide tool were investigated. ANOVA (Analysis of variance) was used to describe the impression of the cutting characteristics. The result determines that the structure of material was the highly effect full factor on roughness of surface and the force of cutting is affected by feed rate [26].

The effect of cutting parameters like feed rate, cutting speed and angle of approach was investigated on roughness in turning process of Al 7050 composite and Al 7050 hybrid composite by using the polycrystalline diamond tool. ANN (Artificial neural networking) and response surface methodology (RSM) is applied for comparison of the experimental results. Cutting speed and interaction of cutting speed and feed rate affect surface roughness. Involvement Graphite particle improves the surface roughness [27].

5. Recycling of composite materials by 3D printing

CFRTPCs (Carbon fiber reinforced thermoplastic composites) with comparatively very high performance have been implied at the ground level for recycling of 3D printing of continuous carbon reinforced poly lactic acid composites. The tensile strength of recycled fiber filament observed during experimentation was much more than originally printed without CFRTP composites, and in bending strength, 25% of improvement was observed. Recovery rate of material was 100% for CF (carbon fiber) and 73% for PLA (poly lactic acid) were gained for a higher environmental and social impact. Use of energy for recycling was near about 67 MJ/Kg, comparison was made of this recycled composite with previous composite which made up with conventional method [28].

Many researches in 3D printing technology give opening to recycle thermoplastics. Using wastage materials to manufacture composites in this manner enhance value to the polymer by developing excellent aesthetic and mechanical properties. Composite filament for 3D printing with differing hemp fiber, harakeke and recycled gypsum contents in recycled polypropylene were assessed and produced for mechanical properties. The highest tensile property observed in 30% harakeke fiber filament [29].
6. Conclusion

Additive manufacturing/3D printing technology is lagging due to higher production time and secondly limited availability of printing materials variety. A composite material offers superior mechanical, chemical and physical properties with higher durability. Combination of two or more materials successfully adopted as 3D printing materials but still much more research and development are required to fulfill the demand of society. After that machining of 3D printed part is more complicated compared to traditional metals because of unavailability in the design of machining especially for plastic parts. Also, the plastic waste is a huge problem now a day for the environment so, significant research and development is needed in a field of additive manufacturing to recycling plastic waste. Main objective of this work is to develop a novel composite filler material for additive manufacturing by recycling the Plastic waste and manufacture a test samples from that developed material. Mechanical characterization and Validation is planned to evaluate from the manufactured composite material for some useful application.

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