A Review on Composite Filaments for Fused Deposition Modeling Process

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Abstract - *Fused Deposition Modeling is a solid based additive manufacturing process which is being extensively used in manufacturing of prototypes and functional parts for different applications such as aerospace , automotive , biomedical , prosthetics , Dental and many more. The process utilizes a solid filament which gets extruded through a heated nozzle and gets deposited over a heated or non heated bed in a layer by layer fashion to reach the completed final part. The present work provides a detailed exploration about the functioning of the process and also the diverse composite filament materials available in the commercial market for different applications and also the filaments developed by researchers all over the world to pursue research to have an insight about the potential of such filaments to become end use parts. The review acts as tool for the budding researchers to understand the diverse composite filaments available with fused deposition modeling.*

Keywords – Additive Manufacturing, Fused Deposition Modeling, PLA, Carbon Fiber

1. INTRODUCTION

Product manufacturing is an important phase in any industry as the designed and developed product is one which meets the expectation of a customer and also ensures the sustainability of the industry in the market. Numerous manufacturing techniques have evolved in the past decades and each one of them has provided their best outcome to the industrial practioners at different timelines. The continuous improvement in technology has degraded the existing method and created revolution in product manufacturing through major technological breakthroughs. The major notable drawbacks associated with conventional manufacturing of products for a long time are relying upon costly machines, highly skilled labour, effective cutting tool, efficient lubrication for heat dissipation, preparation of detailed process plan, higher lead times. The current industrial scenario is changing from decade to decade with substantial amount of research carried out by researchers all over the world to curb or eliminate such drawbacks but still the research is underway. Additive Manufacturing (AM) is a term refers to a group of manufacturing process which creates the object by means of adding layers one over the another. The evolution of addtitve manufacturing has created many viable methods of creating products for diverse discipline with lesser amount of waste and low skilled labour force. The basic principle that drives nearly all AM machines is the creation of virtual solid model then breaking this solid model in to 2D cross sections and feeding this broken data to the machine for the creation of final parts[1].

The different additive manufacturing process that are in industrial practice may be classified based upon the type of material used and methodology for converting the raw material into finished product. Based upon the form of raw material adopted it may be classified as solid, liquid and powder based techniques. The expiry of patents filed towards the different AM process has got expired and it turned the minds of industrialists, researchers and scientists to practice product manufacturing in an unconventional way. Fused Deposition Modeling (FDM) is one of the solid based additive manufacturing process introduced by Stratasys in late 1980's which has the capability to produce parts in the form of prototypes and functional parts by the fusion of a thin filament through a heated nozzle and depositing the fused layer on a heated or non heated bed in a layer by layer fashion. The process has different material options such as thermoplastics, ceramics, composite materials and day by day ne materials have been developed through extensive research to suit the needs of different industries. FDM finds application in diverse domains such as aerospace, automotive, defense, marine and architectural. The parts produced through FDM process have certain disadvantages such as lacking mechanical properties, poor surface characteristics and longer production time. The existence of such disadvantages limited the adoption of FDM process. Day by day researchers and scientists in the field of fused deposition modelling are conducting unstoppable research in bringing out new filaments and optimal FDM parameter findings to cater the needs of different domains which can possess superior mechanical properties , enhanced surface charcateristics and lesser production time.

The commercially available filaments have been adopted for examining its potential in matching the demands for creating prototpes and functional parts. Common filaments such as Acronitrile Butadiene Styrene (ABS) ,Polylactic Acid (PLA),Polyethylene Terethalate Glycol Modified (PETG) , High Impact Polystyrene (HIPS) , Polcarbonate (PC) and composite filaments made out such as carbon fibre reinforced PLA , ABS ,PC/ABS belnd and many more are currently available in the market. Mohammed Raffic et.al [2] has conducted the experimental investigation on HIPS material to evalaue the flexural strength by varying the input parameter through taguchi's experimental design and the authors have identifeid that the infill density is the most dominat fcator affceting all the responses considered. Ganesh Babu et.al [3] has studied about the inflence of FDM parameters over the fatigue strength , printing time of ABS material by varying the input factors such as layer height , infill density and printing speed The authors have analysed the experimental dataset using ANOVA , grey relational analysis and reported that layer thickness is the highly significant factor affceting both the reposnes and printing speed has less significance. Numerous research has been carried out using both the individual and composite filamnets for understanding it's potential to be a suitable candiadate for numerous engineering applications.

2. FILAMENT MANUFACTURING

A filament is in the form of thin wire actually extruded through heated nozzle in FDM machine inorder to deposit over the bed one over the another to reach the end use part. The commercially available filaments are in two different diameters such as 1.75mm and 2.85mm. The most preferable diameter of the filament used for the production and experimental purpose is found to be 1.75mm diameter. The filament produced actually comes in spools with different weight values such as 0.5 kg and 1 Kg for the end users. The filament manufacturing consists a series of steps which has to be followed in a systematic way. The dimensional accuracy of the filament, surface smoothness and roundness are few major parameters which are highly focussed while manufacturing a filament. The manufacturing of filament is carried out in a filament extruder which actually consists a hopper for feeding the raw materials in the form of plastic pellets in to a barrel which consists a screw rod .The temperature of the barrel is set according to the type of filament to be manufactured and the processed plastic pellets inside the barrel is extruded through the nozzle section of the extruder. The manufactured filament is rolled in a spool based upon the requirement. The manufactured filaments may be colored based upon the requirement of the end part.The figure 1 (a) and (b) shows the commercially available PLA filament in different colours and Carbon fibre reinforced PLA in black colour .The manufactured filament comes along with the information about its mechanical, physical, chemical and electrical properties as per the standard testing methods.

FIGURE 1(a) PLA filament in different colours (b) PLA filament with Carbon Fibre Reinforcement

3. FILAMENT SELECTION CRITERIA

The selection of a filament for a product depends upon numerous factors such as strength of the printed final part, dimensional accuracy, surface finish required , flexibility , solubility , requirement of heated bed , difficulty in printing, availability of different colors and apart from that the filament properties such as mechanical , physical , electrical and chemical are also considered. The other major factor which needs to be considered while selecting the filament is the type of machine used for making the final part. Filaments such as ABS, PLA, HIPS and PC may be printed by using desktop machines, but for printing the filaments such as PEEK and other composite filaments industrial FDM machines are required.Exconde et.al [4] has applied multi criteria decision making technique ELECTRE for finding the optimum materials for manufacturing a redesigned breadboard The authors have considered six different materials such as Virgin LDPE , Virgin HDPE , Virgin PET , Virgin PP , recycled HDPE and recycled PET for the material selection process . The material properties such as melting temperature, glass transition temperature, melt flow index, coefficient of thermal expansion and material cost. The authors have reported that recycled PET material is the most suitable one for making the redesigned breadboard as it has outranked with other materials considered in the study. Table 1 shows the few commercial FDM filaments available in the market and their potential applications.

TABLE 1. Commercial FDM Filaments in Practice

S.No	Material	Applications	Remarks
1	ABS	LEGO Bricks and Bicycle helmets	High strength and durability
2	PLA	Phone Cases , High Wear Toys and Tool Handles	Easy to print and biodegradable
3	PETG	Printer parts and Protective components	Flexible and Susceptible to moisture
4	TPU	Toys , Phonecases and Wristbands	Extremely flexible and slow print speed
5	Nylon	Hinges , Buckles and Gears	High strength and durability , Typically expensive
6	PC	Medical equipment parts and vending machine parts	Extremely strong and requires high print temperature

4. COMPOSITE FILAMENTS

A composite material is a combination of two different materials with varying properties combined together through a standard method to provide better physical, mechanical and other related properties with a considerable enhancement. The FDM filaments that are available in the market are mostly common filaments made out of single material which finds applications in making of prototypes and very few functional parts. The mechanical properties of the parts manufactured through single material FDM filaments possess lacking mechanical properties in comparison to their counterpart injection moulded plastic parts which actually makes them as the least suitable candidate for engineering applications. In the commercial market very few composite filaments such as carbon fibre reinforced PLA, carbon fibre reinforced ABS and PC/ABS blend. Researchers all over the world has created their own composite filaments to unveil their potential for functional engineering applications by varying the proportion of the reinforcement, by differing the reinforcing phase of the composite material.

Celine Badouard et.al [5] considered three different matrix phase materials such as PLLA , PBAT and PBS for creating composite filament by using flax fibres as the reinforcing phase to understand the potential of varying the composition . The authors have prepared pellets made out of both the matrix and reinforcing phase materials to convert them as filaments of diameter 2.85mm.The composite filaments produced are further printed in the form of tensile testing specimens to evaluate their tensile strength. The authors have reported that the selection of matrix phase for the composite has shown a considerable change in the final properties of both the injected and printed tensile testing specimen. The authors have concluded that PBAT is found to be the most suitable matrix phase material among other matrix phase candidates. Mindaugas Bulota and Tatiana Budtova [6] studied about the morphology and mechanical properties of composite filaments made with PLA as matrix material and Algae as the reinforcing material in three different colors such as green , red and brown. The composite filaments were prepared by using melt mixing method by varying the size of algae ranging below 50µm and between 200µm and 400µm. The algae concentration has been varied from 2 to 40%. The authors have studied about three different aspects such as algae morphology, composition and surface properties The authors have conducted tensile testing of the prepared composite material with algae as the filler material has reported that the tensile mechanical characteristics of composites decreased with increase in algae concentration and the young's modulus of composites with 40wt% algae concentration exceeded the value of neat PLA. Aumnate et.al [7] fabricated composite filaments with ABS as the matrix phase and grapheme oxide as the reinforcing phase to test their potential for different applications through 3D printing The authors have prepared the filament through two different methods such as dry mixing and solvent mixing method The authors have studied the mechanical properties of the printed composite filament and reported that the addition of 2wt% grapheme oxide with ABS has shown considerable improvement in mechanical properties of ABS The authors have also reported that the filament prepared through dry mixing method failed to print due to the aggregation of grapheme oxide leading to clogging while printing. Prabaha sikder et.al[8] developed composite filaments for the manufacturing of orthopedic and dental implants by considering polyether ether ketone as the matrix phase and amorphous magnesium phosphate as the reinforcement phase . The authors have observed that the reinforcing phase considered have very good dispersion with the matrix phase and they have conducted various tests such as thermogravimetric analysis , rheological analysis to understand the effect of adding reinforcing phase with PEEK . The authors have reported that the addition of amorphous magnesium phosphate with PEEK is found to be a suitable candidate for manufacturing implants. Umit cevik et.al [9] performed a detailed review about the various research work carried out by using metal polymer composite material in different applications .The Authors have reported that the addition of metallic elements with plastics does not ensure improvement in mechanical properties of the end part. Thomas distler et.al [10]produced FDM composite filament made with PLA and Bioactive glass for the manufacturing of scaffolds. The authors have reported that the filaments containing bioglass exhibited bioactivity and it can be used in the applications of bone tissue engineering due to the increased osteogenic differentiation triggered in the manufactured scaffolds. Kazi et.al [11] analyzed the presence of chopped carbon fibre in short form with ABS as the matrix phase through various analysis such as thermogravimetric analysis , differential scanning calorimetry and thermomechanical analysis to understand the thermophyscial properties of both Neat and carbon fibre reinforced ABS material. Dechuan Hua et.al [12] manufactured composite filaments made out of PLA and multi wall carbon nano tubes for the application of soft robotics through fused deposition modeling to develop an excellent photo thermal material suitable to act as actuators.Ester. M.Palmero [13] produced metallic composite filaments using two different metallic elements such as aluminium and stainless steel with ABS material. The authors have studied about the filling factor of the metallic elements and reported that smaller particle size and higher size distribution have facilitated the fabrication of continuous filament. Mohd et.al [14] presented a detailed review about the fabrication of composite filament for biomedical applications. The authors have insisted for the optimization study for input process parameters, in vitro and in vivo study of the developed composite filaments need to be studied for manufacturing biomedical scaffolds. Zuoimin lei et.al [15] developed highly electrical conductive composite filaments using conductive silver pastes and polyvinyl butyral for the applications in Printed Circuit Board , RFID and electronic paper. From the literature survey carried out it can be thoroughly understood that the area of composite filaments are increasing in a rapid manner due to their potential to acts as suitable candidates for applications such as biomedical, dental , aerospace , automotive and conductive electric circuits.

5. CONCLUSION

The concluding remarks of the present study are outlined herewith

1. Adoption of natural fibres as reinforcement is fastly growing in the area of 3D printing filaments

2. The presence of reinforcement has shown both positive and adverse effects over the mechanical properties of the material studied.

3. The fibre reinforcement characteristics such as orientation , thickness , length and the way of dispersion has strong effect over the measured mechanical properties such as tensile strength ,young's modulus

4. Development of bio based composite filaments for fused deposition modeling is another interesting research area gaining momentum currently.

5. The development of new composite filaments are focused towards the applications of medical , dental , electric circuits and progressing at faster rate.

6. For the development composite filaments optimization study may be carried out in order to identify the potential parameter setting to enhance the desired properties of the final part.

7. Modern techniques such as machine learning and deep learning may be incorporated with the experimental dataset to unleash the hidden potential of composite filaments to suit them as appropriate candidates for diverse applications.

8. Apart from natural fibres , addition of metallic elements as reinforcing phase also considered in many research studies

9. Comparing to petroleum based plastics in making composite filaments plastics made from natural resources which are biodegradable like PLA are mostly considered.

10. More research opportunities are available in the area of optimizing the FDM process parameters for composite filaments with natural and metallic reinforcements.

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