Issues in dual material fused deposition modelling with polycarbonate - Acrylonitrile butadiene styrene (PC-ABS) on a desktop 3D printer

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ABSTRACT

Additive Manufacturing encompasses a complete range of technologies where parts are fabricated by material addition essentially layer by layer. Fused Deposition Modelling (FDM),being a cost-effective technique, is one of the popular additive manufacturing technologies. Owing to the simplicity of its material delivering system, FDM is capable of manufacturing parts in multiple materials and is known as "Multiple Material Extrusion Technology". Polycarbonate is the strongest known material as far as FDM is concerned but difficult to manufacture using a desktop 3D printer due to difficulties in processability. By using multiple extrusion of Acrylonitrile Butadiene Styrene with Polycarbonate, this paper aims to explore the possibilities of fabricating composite parts in situ on a desktop 3D printer.

1. Introduction

Additive Manufacturing (AM) is one of the upcoming technologies in manufacturing. In Indian market, the growth of the technology is promising. The prospective presented by AM in the field of prototyping is astounding hence the technology is also sometimes referred to as Rapid Prototyping. AM came to be used on a commercial level in 1987 with stereolithography (SL) from 3D systems, USA, followed by NTT data CMET and Sony/D-MEC in Japan and Electro Optical Systems in Germany [1]. This set-in motion serious effort in developing the other non-SL technologies. In 1993, fused deposition modelling (FDM) or Free Form Fabrication (FFF) by Stratasys, solid ground curing (SGC) by cubital and laminated object manufacturing (LOM) by Helisys were developed. FDM is an extrusion-based technology where roads of molten thermoplastic are laid down layer by layer to build a part in three dimensions as per the g-codes. It is the most widely used technology for prototyping and with the recent development in materials and technology and the extensive research, it has made its presence in functional parts manufacturing also. The compact desktop setup and the use of variety of non-toxic, strong industrial grade materials has given FDM a pride place in AM technologies [2]. But there are still issues while printing certain materials, like polycarbonate (PC), Nylon, polyether ether ketone (PEEK) for example, with a desktop printer. This paper highlights the issues faced while printing parts with pure PC material and explores the possibility of printing PC in conjunction with Acrylonitrile Butadiene Styrene (ABS) and the issues faced there in and possible solution on a desktop FDM printer. The next section discusses different AM materials available Multi material extrusion technology (MMET).

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2. Materials for FDM

FDM uses amorphous thermoplastic material formed in wires of standard diameter wound on spools. Amorphous thermoplastics have low melt temperatures. PLA is used for FFF very often because of ease of use. It is less prone to warpage and layer separation, gets printed on low temperature and has medium flexibility and strength. It is biodegradable and doesn't gives off bad smell. Acrylonitrile Butadiene Styrene commonly known as ABS has high durability and strength and is the second most commonly used material. It has capacity to withstand high temperatures and is moderately flexible. Polycarbonate (PC) is a heat resistant thermoplastic with good mechanical properties. Polycarbonate is very strong as filament and is extremely durable with high impact resistance. It can withstand temperature up to 110⁰ C and is transparent.

The table lists various common materials used in FDM technology [3]:

Table 1
Material in FDM.

Standard Filaments	Other Special Filaments	Professional Filaments
PLA (Polylactic Acid)	Wood	Carbon Fibre
ABS (Acrylonitrile Butadiene Styrene)	Metal	PC/ABS
PET (Polyethylene Teraphthalate Glycol)	Biodegradable	HIPS (High Impact Polystyrene)
TPU (Thermoplastic Polyurethane)	Conductive	PVA (Poly Vinyl Alcohol)
Nylon	Glow in dark	Wax
PC (Polycarbonate)	Magnetic	ASA (Acrylonitrile Styrene Acrylate)
	Colour Changing	PP (Polypropylene)
	Clay and Ceramic	POM (Polyoxymethylene)
		PMMA (Polymethyl Methacrylate)
		Cleaning Filament
		FPE (Flexible Polyester)
		PEEK (Polyether ether Ketone)

To enhance properties of available polymer filaments, fibre- reinforced polymer composites and polymer blends are used. Composite material in FDM can be obtained in situ or using already blended filaments [4]. For already blended filaments, there is a base polymer to give strength to the filament, a tackifier for flexibility, the surfactant for better diffusion of additives in solution and a plasticiser for better viscosity [5]. Two different materials are mixed in a blender and then extruded multiple times to deliver a homogenous composite filament [6]. Additives that are added to the base material for strengthening purpose must enable effective extrusion and should have low viscosity.In situ extrusion of multiple material, may also help in forming composite materials [7]. This is known as Multi Material Extrusion technology.

3. Multi-Material Extrusion Technology (MMET)

MMET is an extension of FDM wherein more than one extruder is used to deposit molten material. FDM is the promising process for multi material additive manufacturing given the simplicity of material delivering systems [8]. There are FDM machines available enabled with two extruders which allows the deposition of model material and support material separately. Two or more extruders can also be used to print parts in different materials for functional requirement or same material in different colour for aesthetics. For educational purpose, MMET printed models provide better understanding and visualisation [9]. This technology enables manufacturing multifunctional parts which can incorporate variable materials without assembly requirement [8]. This is achieved by designing the parts at the initial stage for multi material extrusion. M. Sugavaneswaran and G. Arumaikkannuin their work developed a script in CATIA VB to model Randomly Oriented Multi Material tensile specimen and compared the mechanical strength to the pure elastomer component and the former found to have improved stiffness [10].

CAD modelling of the parts to be manufactured by MMET when done as per the design guidelines for two or more material, can result in parts with required strength. This can be done by incorporating best properties of two different materials having different costs into single design. Using the high strength and costly material for critical areas and making remaining part in other material of moderate strength can considerably reduce cost without affecting the functionality of the part. This is a way of blending two polymers so as to derive the best of both. The parts can be specifically designed for the ease of 3D printing while taking into consideration the overhangs, minimum wall thickness, warping and level of detail.

Another factor that can be effectively controlled using MMET is, the cost of printing. It can be optimised by combining two or more type of materials at strategic locations. As shown in their study on multi-material, multi-technology FDM, David Espalin, Jorge Alberto Ramirez, Francisco Medina and Ryan Wicker integrated two legacy machines to utilise four nozzles to deposit two different material to achieve variable road width deposition and layer height [11]. The integration required a customised graphic user interface (GUI) and program and mechanical program. Variable road width and layer height deposition helped in reducing surface roughness by 38-55% and reduced the printing time of a square prism by about 53%. Reduced printing time results in reduced cost.

Multifunctionality through MMET is explored more in the area of electronics and bio-fabrication, tissue-engineering and bio-plotting due to the availability of wide variety of processable bio-materials. Recent developments involve embedding wires and foils in 3D printed thermoplastic parts [3][12][13]. Along with enhanced electrical interconnection such embedded wires and foils act as reinforcement and improve mechanical strength.

Utilising the benefits of MMET in the field of bio-engineering, 1. scaffolds are prepared which have natural bone and teeth like structure [14][13], 2. Organs and tissues have been printed which are fully functional [15]. For study of internal organs for example heart, multi-coloured models are 3D printed for better understanding [9]. Dimitri Kokkinis, Manuel Schaffner & Andre´ R. Studart have used multi ink dispenser, pre-loaded with magnetically responsive ink and two component mixing unit. This enabled them to have control over the local composition of the material by applying low intensity magnetic field. The objective is to pave the way of manufacturing functional heterogenous material.

Using the advantage of MMET the present study attempts to find out a way to print PC on a desktop 3D printer using ABS as a supporting material.

4. Polycarbonate- Acrylonitrile Butadiene Styrene (PC-ABS) Blend

Polymer blends are successfully used in various industrial and engineering applications to derive best of both the polymers. Polycarbonate-Acrylonitrile Butadiene Styrene (PC-ABS) is the most common blend. It has good mechanical properties and impact strength [3]. PC-ABS blends combine the flexibility of ABS with strength and heat resistance of PC. The composition of available PC-ABS filaments is not known due to market strategies and competition. So, by varying the composition of both materials (PC and ABS) and taking advantage of multi material extrusion technology of FDM it was hypothesised that it can be possible to print parts with considerable strength in PC-ABS on a desktop 3D printer too.

On a desktop 3D Printer, printing any material other than PLA is challenging. To effectively print a part out of ABS it is required to have an enclosed chamber. The printing temperature of ABS is around 210^{o}C to 250^{o}C. It has a tendency to shrink when it comes down from extrusion temperature to room temperature resulting in separation from the bed also known as warping. Having a heated bed (90-110 ^{o}C) and using proper adhesive helps remedy this problem. In the absence of enclosure, layer separation takes place at layers farther away from bed for the same reason.

5. Methodology

The steps followed to carry out the sample preparation are as follows:

1. Selection of Standard Sample as per ASTM
2. Sample cross-section for 50-50% and 70-30%
3. 3D Model Preparation
4. STL and G-code preparation for dual material
5. Sapmle 3D Printing in dual material

6. Experimental Procedure

It was required to 3D print Polycarbonate on a desktop 3D printer Triostar Dual 2.0. The printer is capable of 3D printing in dual material. There are a lot of issues faced during 3D printing PC alone. It requires a hot end capable of extrusion temperature as high as 310°C and heated bed with 120°C. PC is hygroscopic i.e. it absorbs moisture from air when kept in open. It swells on moisture absorption resulting in increase in filament diameter. Its viscosity also reduces. This causes unregulated flow rates and over-extrusion. This is also a major set-back in 3D printing with PC. PC also cools fast and rapidly cooled print warps at the corners. Sometimes the layers also get separated. Even with a pre-baked PC filament it was very difficult to print with it.

Since PC-ABS is a common blend, it was concluded that to avoid warping PC should be printed using ABS raft, which was successful. But even with using ABS as raft the layers of the parts got separated at higher levels. Raft (Figure 1) is used to build a strong foundation for the parts and helps better adhesion to bed and prevent warpage.

In FDM, the layer adhesion takes place by liquid fusion [3]. When molten plastic having a low viscous flow is deposited on the previous layer, both layers stick together. For two material to bind together properly it is required to have better adhesion at contacting layers. PC is difficult to process, has poor chemical resistance and is costly. ABS has good processability, chemical resistance, low cost but has poor heat-resistance. PC-ABS blend has superior mechanical properties of high heat resistance and toughness and better processability. PC sticks to ABS making it possible for them to be printed in situ by MMET. It was next hypothesized to print PC and ABS alternatively in two different ratio and test the samples for strength.

The sample was designed as per ASTM Type I specification as shown in Figure 2. The first sample was designed to have a 50-50 composition of PC and ABS as shown in Figure 3. ABS and PC layers were sandwiched vertically. In their study Heechang Kim et al. found out that layer adhesion in horizontally sandwiched dual material samples is better than when the material is aligned vertically [16]. It is so because the nozzle applies some pressure to enable layers to adhere to each other. ABS and PC are both prone to layer separation at heights hence the standard thickness was divided equally and it was decided to keep the maximum height of each layer as 1mm.

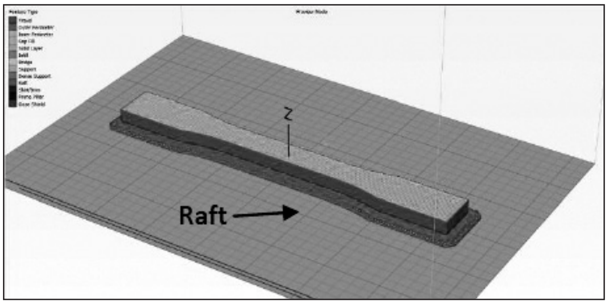

Fig. 1. Raft

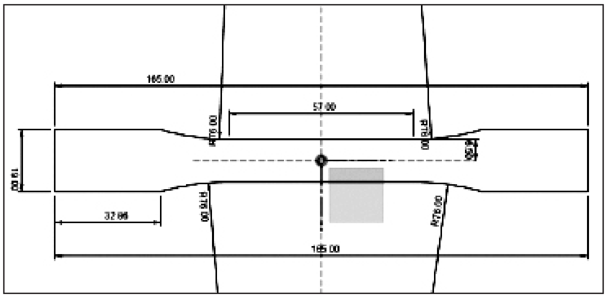

Fig. 2. Dimensions of specimen ASTM D638 Type I

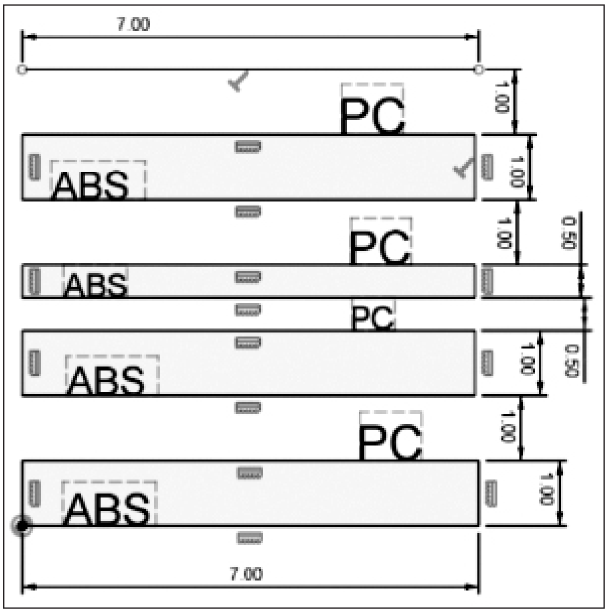

Fig. 3. PC-ABS 50-50% sample specimen schematic cross-section

Orientation and Raster Angle selected for the sample specimen was flat and +45/-45 respectively. The on edge and flat +45/-45 for PC have similar tensile strength [17]. The first section of the specimen which was oriented flat to the bed was ABS. The maximum extrusion temperature of the Triostar Dual 2.0 3D printer is 250°C and maximum bed temperature is 110°C. Print settings were kept for maximum possible temperature with printing speed 60mm/s or

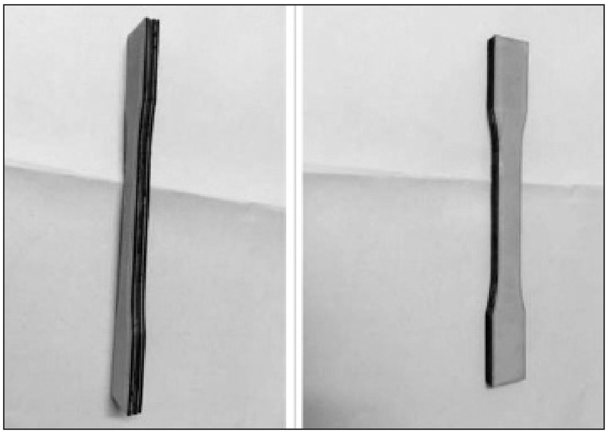

Fig. 4. PC-ABS 50-50% 3D printed Sample 1

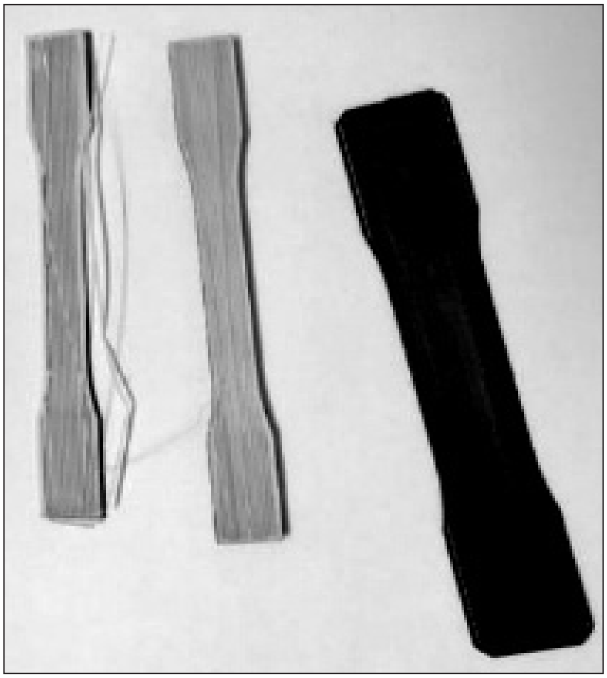

Fig. 5. PC-ABS 50-50% 3D printed sample 2

3600mm/min. Polyetherimide (PEI) or ULTEM sheet was used over heated bed along with ABS juice used as adhesive and ABS raft to ensure proper first layer adhesion. The printing was carried out in an enclosed chamber to maintain heat inside the chamber so as to avoid layer separation.

7. Results and Discussions

Three sample specimens were 3D printed in dual material 3D printer with Polycarbonate and Acrylonitrile Butadiene Styrene. The first sample got printed but it suffered slight over- extrusion as shown in Figure 4.

The second sample also got printed but layers

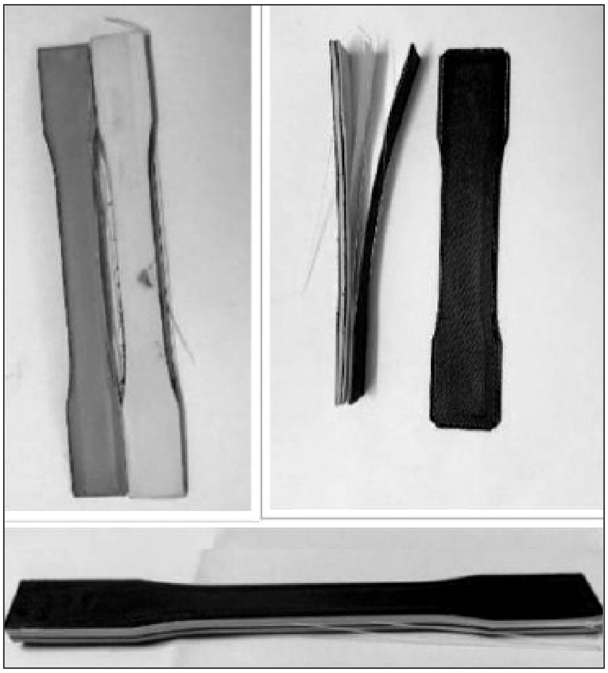

Fig. 6. PC-ABS 50-50% 3D printed sample 3

separated from each otherafter the sample was taken out of printer and separated from raft (Figure 5).

The third sample got warped (Figure 6) inspite of all the precautions taken. Layer separation occurred in third sample too.

8. Conclusion

The consistency in 3D printing dual material PC-ABS 50-50% samples could not be maintained. Two out of three samples suffered layer separation which indicates that the heat could not be maintained in the printing chamber. Warping of the sample from the raft occurred because of the rapid cooling of material and inability to maintain chamber temperature. High extrusion temperature could not be achieved due to the limitation of the 3D printer. It can be concluded that to effectively print PC-ABS on a desktop 3D printer, high extrusion temperature and heated chamber is needed. This gives scope of further research on the possibilities of 3D printing PC-ABS specimens and evaluating other output parameters like tensile strength and manufacturing time for the same.

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