Feasibility Investigations on the Development of Hybrid Pellet-Based Extruder with Fused Filament Fabrication

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Abstract Quintessential additive manufacturing has established Fused Filament Fabrication (FFF) as the major technique due to ease in handling of the equipment. Despite limitations such as restricted material choices, usage of FFF has become de facto among 3D printing enthusiast. Although several independent researchers, industry and academia have tried to use pellet-based extrusion as a prominent method for additive manufacturing, still the respective field has relatively less accessibility and requires more handling effort compared to traditional filament extrusion. The current research focuses on the validity of pellet-based extruder in a hybrid form factor to rectify its handling issues and, henceforth, its credibility when compared to a filament extruder. Thus, experiments are conducted using Acrylonitrile Butadiene Styrene (ABS) and Ethylene-Vinyl Acetate (EVA) in order to validate the developed system. The research is also validated by comparing the part quality with numerous diverse test parts for validation of pellet extruder in comparison with conventional filament extruder. The presented research also explores the printability among various materials and methods.

Keywords Additive manufacturing · 3D printing · Fused filament fabrication · Pellet · Extrusion · CAD

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1 Introduction

Additive manufacturing, once viewed as a breakthrough in manufacturing sector, has plateaued in recent years. Despite being applied in varied forms and processes, such as Fused Filament Fabrication (FFF), Laser Engineered Net Shaping (LENS), Selective Laser Sintering (SLS) and Selective Laser Melting (SLM), its application is still limited to prototyping and selective test cases in medical and aerospace sectors.

Among these methods, FFF is the most popular globally for the aforementioned purpose. Due to easy handling and relatively inexpensive factor, the prominence of FFF is widely justified among the masses. Largely employed for concept validation among researchers, it has so far provided enough support to shape blooming ideas but with years going by, the eligibility of FFF is gradually decreasing. This is attributed to factors such as limited application of materials in FFF processes, exhaustion of novel concepts/ideas regarding material combination and its application, along with that, stagnant growth in the FFF community. Furthermore, a shift in interests of scientific stakeholders due to earlier mentioned factors has also caused negligence in innovation [3].

Alternatively, some academicians have tried to opt for different techniques in order to widen the range of additive manufacturing. One of those techniques is pellet extrusion which involves layer-by-layer deposition of material present in pellet stock form instead of filament form [7]. This enables to incorporate mixtures and combinations of several materials in predefined proportion, without worrying about its mechanical properties due to imminent filament conversion from its initial raw form. Along with that, traditional injection moulding principles can be applied for simulating the workflow behaviour initially. Despite several advantages, its usage is still not prominent in the scientific community. The reasons can be credited towards the lack of professional equipment in the market dedicated towards pellet extrusion additive manufacturing [2].

The present study presents on one such pellet extrusion system developed in house with the ability to alternate between both traditional filament extrusion and pellet extrusion [4]. The details about the design and development of the pellet extruder are published elsewhere. The independent setup can be mounted and driven through the open-source software such as Ultimaker Cura with minor tweaks in settings [10]. The design was validated and optimized via various methodologies in order to calibrate the pellet extrusion hardware with commercial filament extrusion setup which is published elsewhere. Additionally, experimental analysis of fabricated parts also has been performed in order to validate its competence in comparison with conventional FFF technique. Its printability is also tested by throughput analysis of various material not compatible ordinarily with filament extrusion system. Along with that, throughput from different nozzle sizes is also explored [9].

Section 2 includes the discussion on the performed experiments with the apparatus, Sect. 3 is the analysis of results by the experimentation, Sect. 4 lists some issues inferred during the result analysis, and Sect. 5 concludes the presented research work.

2 Materials and Methods

The experimentation utilized diverse materials having different mechanical properties and behaviour such as toughness and elasticity. Figure 1 shows the material in pellet form which was used for the test patterns with ABS and EVA, respectively. A constant rate of pellet input was established beforehand in order to smoothen the material flow across the extrusion process resulting a consistent melting. ABS is tough and rigid, while EVA is an elastomer which cannot be used in filament form. Thus, the pellet extrusion system adds a new dimension of materials especially flexible materials which are strenuous to mould in filament form and also sometimes fails the printing process due to buckling in the extrusion's material feeding system [6]. The pellets utilized in the study size at an average under 3 × 3 × 3 mm.

2.1 Pilot Experimentation

Initially, the extruder had printed some elementary prints such as filament of different nozzle sizes and filaments with different print speeds, with varied temperature, with different materials, etc., to check the viability of the extruder. Some of these throughputs built using the pellet extruder are shown in the forthcoming section along with the throughput of extreme diameters. These filaments are necessary to understand the repeatability of the extruder and versatility using different types of materials [5].

These experiments were designed with optimum process parameters to get a clear idea of extruder's extruding ability and consistency along with its repeatability. The observation from the experiment establishes the foundation of the pellet-based extruder towards extruding full-fledged parts. The process utilizes the extruder at 250 °C of extrusion temperature, 25 mm/s of print speed, 25 mm/s of feed speed and 0.6 mm of standoff distance from the printing bed for ABS parts and, similarly, 100 °C of extrusion temperature, 25 mm/s of print speed, 25 mm/s of feed speed

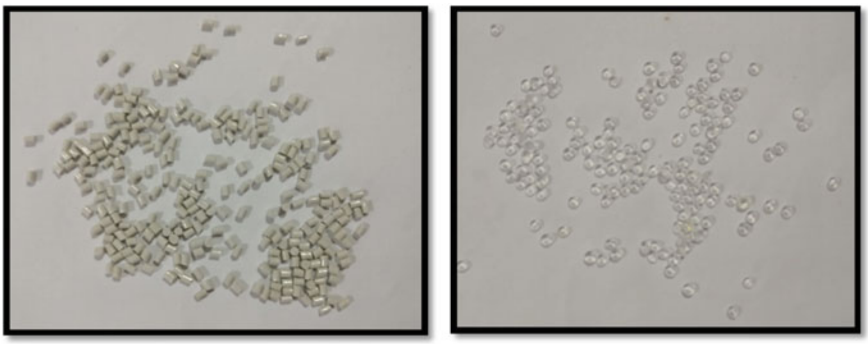

Fig. 1 ABS and EVA pellets

and 0.6 mm of standoff distance from the printing bed for EVA parts. The details on the parameter optimization for the respective pellet extruder and its calibration with filament extruder firmware and hardware via various Design of Experiments methods are published elsewhere.

2.2 Fabricated Parts

This section shows the printability of the pellet-based AM extruder with different nozzle size from 0.4 to 1.5 mm nozzles. Depending on the kind of application, either can be used. Here, the nozzle used to print different parts is 1.2 mm diameter in size due to its high flowability and low back pressure on the feeding auger.

This indicates that the parts printed via the pellet-based AM extruder have the accuracy and ability to print standard parts which can be controlled with an open-source slicing software like Ultimaker Cura. Figures 2 and 3 prove the aforementioned points and are discussed in detail in forthcoming section.

3 Results and Discussion

The various experimentation resulted in different learnings about the validity of the pellet extruder, and also, exploration is done in the area of the possible commercialized version of the hybrid extruder in current scenario. Some of the fabricated

Fig. 2 Microscopic image of EVA throughput

Fig. 3 Microscopic image of ABS throughput

parts are in direct connection with standard filament extrusion systems which also helps understand the merits and demerits of the system. Furthermore, the analysis of the different parts and throughput built from the pellet extrusion system enables to comprehend the further scope of design and parameter modification which can be improved in the setup.

3.1 Pilot Experiments

The results of the initial experiments depict that the extruder shows positive effect on changing the process parameters such as temperature and nozzle sizes. The microscopic image of the filament extruded shown in Figs. 2 and 3 displays no signs of under-extrusion or over-extrusion, thus negating the possibility of the filament stretch or accumulation. Additionally, it also verifies the printability of pellet extruder across various materials from recycled ABS to elastomer EVA, without any burrs. The throughput of the pellet extruder with different materials of extreme characteristics such as ABS and EVA shows the compatibility of the extruder with tough as well as flexible materials. Conventionally, the flexible materials are difficult to print with FFF extruders due to buckling issue and also provide fewer permutations of composite materials, which is not the case with the pellet extruder. The diameter variation is measured to check the repeatability and consistency of the pellet extruder. The following Table 1 presents the details of the deviation of diameter with different material.

Thus, the variation in diameter of the throughput is also found to be less than 0.1%, ascertaining the repeatability of the extruder's accuracy. The image shown in Fig. 4 shows the versatility of the extruder setup with the ability to print via different nozzle sizes from 0.2 to 1.5 mm. Furthermore, the tensile specimens printed as shown in Fig. 5 involved different extrusion parameters such as variation of print speed and nozzle temperature [1].

Table 1 Theoretical and actual throughput

Material			
ABS		EVA	
Nozzle size (mm)	Actual throughput diameter (mm)	Nozzle size (mm)	Actual throughput diameter (mm)
0.40	0.40	0.40	0.39
1.20	1.20	1.20	1.18

Fig. 4 Throughput from nozzle of 0.4 and 1.5 mm diameter

Fig. 5 Tensile specimens printed with ABS

3.2 Fabricated Parts

Thus, the upgraded FFF printer possesses a hybrid printing feature which can print through both filament and pellet material. The pellet extruder enhances the printability of the 3D printer with its ability to print various materials unconventionally not available commercially in filament form. In addition to the hardware, the use of an open-source firmware and software to operate the pellet extruder and synchronize with software provides the ingenuity to add and modify observed changes in parameters, in order to fine-tune the extruder for user-defined operations on selective materials/parts.

Figure 6 shows a simple cube built using the pellet extruder and also the standard boat benchy part which is used for calibration of various filament-based systems and fine-tuning its output by tweaking its parameters [8]. It incorporates various complex features such as roundness and inclination to measure and analyse the accuracy of the printing system in unison.

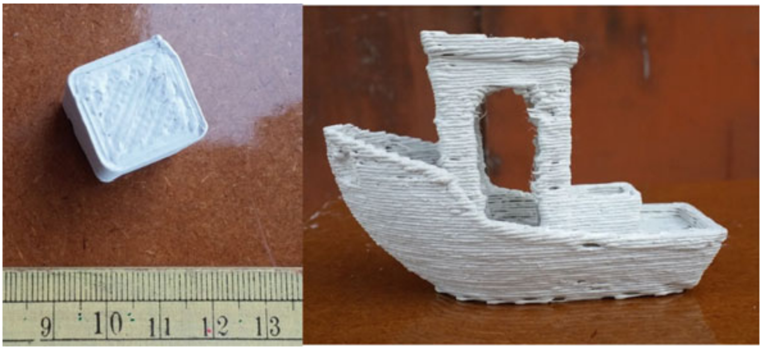

Fig. 6 Some more parts built using pellet extruder

4 Issues and Challenges

During the development, there are many factors which influence the printability of the pellet extruder. These factors are further classified as external and internal factors, which include heat transfer, cooling rate, design optimization, etc. To rectify these issues, changes must be accommodated and justified within the range of calculated operation parameters. The observed shortcomings of shrinkage and rough surface blobs are further rectified by using a nozzle of smaller size. The existing pellet extruder has the allowance to opt between nozzle sizes which is as convenient as changing nozzle in standard FFF printers. The fabricated parts such as tensile specimens and boat benchy further verify the printability of the pellet extruder among a variety of shapes and sizes.

Additionally, in future a gantry system can also be manufactured having an extruder storage tread head, providing the accessibility to choose from filament-based and pellet-based AM extruder on the same machine thus enabling large possibilities of hybrid printing for aerospace and automotive turbo-machinery sector. Furthermore, due to change in its input material form from filament to pellet, extensive use of flexible polymer can also be employed irrespective of its buckling strength, which is generally limited to printability in the filament-based printer.

5 Conclusion

The conducted research explained the possibility of a pellet-based extrusion system with a comprehensive analysis between standard parts built with either extruder. The development of pellet-based extruder was done in such a way that a commercial FFF printer can be modified and utilized as pellet-based system without any major modifications on printer's motion chassis. Along with the successful upgrade, some throughputs extruded with different parameters and hardware have been investigated also, to establish the groundwork for justification of the developed setup. Additionally, different materials were also used to validate the increase in printer's applicability in comparison with traditional FFF printer.

The resulted output illustrates that the direct pellet fabricated parts are closely comparable with conventional FFF parts. The post-processing attributes such as shrinkage factor, overall strength and surface finish are similar to the standard systems. Furthermore, the manufacturing of complex parts such as boat benchy and standard tensile specimens widens the spectrum of the pellet-based extrusion system application. In future, several different material combinations can be tested for further research in the respective field. A gantry system for switching between pellet and filament extruder can be built to add an industrial perspective to the extrusion system.

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