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DESIGN AND ANALYSIS OF PLASTIC EXTRUDER AS 3D PRINTER HEAD (FDM).

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ABSTRACT: The aim of this paper is to develop an extrusion process-based 3D printer head for thermoplastic materials which can enable low-cost production and accommodate multi-material in the same setup. 3D printers employ a process called additive manufacturing, in which a product is shaped by addition of material layer by layer until the final shape is formed. The 3D printer with FDM technology has restriction due to its characteristic limitations. The other problems include, but not limited to, high time required for production, limitation of existing printers to use specific plastic type (e.g. ABS), changing of material for 3D printing is not possible in the same setup, and as whole an expensive 3D printing process. The proposed design of 3D printer head uses the basic extrusion process eliminating the need for switching filaments resulting in production growth with multi-color and multi-material advantages.

Keywords: Single Screw Extruder, Fused Deposition Modeling (FDM), 3D Printer head.

INTRODUCTION

Recent advancements in technology Three Dimensional printing has now enabled the employment of a vast scope of materials (metals, ceramics and polymers) (Abilgaziyev *et al.*, 2015). Hence, opportunities for trade exist for this specific technology type in vide areas spanning from the medical field to transportation industry, from anatomical models to automobile, from aerospace to construction of buildings, and it, embodies a type of 3rdindustrial transformation, in which manufacturing and industry are found on a entirely new model. Today, 3D printers come in many different types and varieties according to their usage, and are being used in homes, schools and different industries (Arbaoui *et al.*, 2015). A wide variety of 3D printers rely on different tools and technologies, and procedures to use and print different range of materials but the final 3D print object is created using the same methodology of adding material together (material fusing together) typically layer by layer (Blandon *et al.*, 2015; Drotman, 2015). Some common 3D printing methodologies include Fused Deposition Modeling (FDM), Stereolithography (SLA) (He *et al.*, 2017), Powder Bed Fusion (Junk and Kuen, 2016), Material Jetting (Oo *et al.*, 2018), Binder Jetting.

Fused Deposition Modeling (FDM) is one of the popular technologies due to its easiness. In FDM, a filament of thermoplastic material, from a coil is supplied to extrusion nozzle which then passes through the heater with the required melting temperature (Teterin *et al.*, 2016). The object is printed layer by layer with the flow of the melted material. Even though many technological improvements have been accomplished in the FDM process, there are still some limitations. Firstly, the speed of printing is relatively low if compared with other printing methods. Second, the process has been limited to print only one type of material at a time.

This paper addresses the above-mentioned problems of high time utilization and material limitations in FDM process, by introducing a 3D printer head based on extrusion process that could save printing time and allow utilization of variety of material filament.

MATERIALS AND METHODS

Htin Lin Oo, Kyaw Zaw Ye, Ye Htet Linn discussed the complete design and temperature regulator system of the 3D printer in (Junk and Kuen, 2016). They proposed an effective design of control system for heating actuators and stepper motors for 3D machine. Power dissipation for the heating block is regulated by changing the duty cycle of PWM. For a proper ABS adhere to the printing platform, they introduced a vinyl sticker, a plastic type to the heat bed platform. They suggested two L-profile aluminum bars to carry the weight of extruder and to suspend the nozzle 0.8mm above the platform for a sufficient extruded plastic adhere. Results obtained during their study gives us detailed technical information regarding extruder heater and its control mechanism. Yin He, Wen Quangang, Lin Gang, Li Tingting discuss the impediments in the smooth performance of extrusion mechanism of FDM 3D printer in (Teterin *et al.*, 2016). They illustrated the necessity of better speed control methods of stepper motors, acceleration and deceleration, start and stop will greatly reduce any shock or impact on the equipment. Their research aims to be helpful in designing the material flow speed parameters for the proposed extruder. (He *et al.*, 2017) present an experimental and economical portable system for extrusion in which superior quality filament is produced with constant sized profile throughout its span. Through the system, new materials(composite) can be generated for 3D printers. During their study, it was found out that in order to acquire a constant extrudate through its length, especially during the continuous temperature modes and minimal external stimuli on the hot filament; the temperature of extrusion should be 220 Celsius and natural air cool be allowed, due to which filament, keeps flexibility during three seconds. When velocity of filament from nozzle is average i.e: 6 m/min, the plastic section of filament is around 30 centimeters. Their study will prove supportive in multi-material design parameters for the extruder. These studies provide a base line for our research work in the development of an extrusion process-based 3D printer head.

Design Considerations: A commercially available software known as Solidworks was used to design and assemble the extruder model. The proposed model consists of six main parts namely barrel, screw, nozzle, hopper, heaters and gearbox as shown in fig 1. The exploded view of the design of the 3D printer head extruder is shown in fig 2 and list of elements for the design is shown in Table 1.

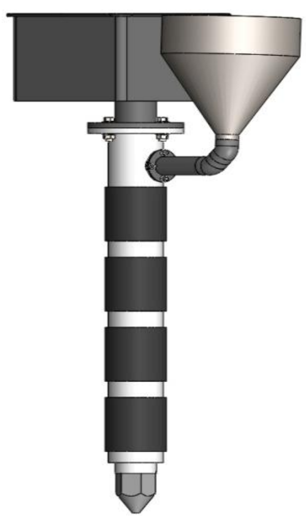

Figure 1 3D view of the proposed 3D printer head

The total length of the extruder including the gearbox stands at around 23cm only which is sufficient to install and even use in a miniature CNC machine. The length of barrel excluding nozzle support stands at around 167mm with dimensions as shown in fig 3 and inner diameter dimensions of barrel are shown in fig 4. The dimensions of extruder screw are shown in fig 5. The maximum diameter of the screw is 11mm with screw pitch at 8mm with 15 revolutions. More dimensions of extruder model are discussed in Table 2.

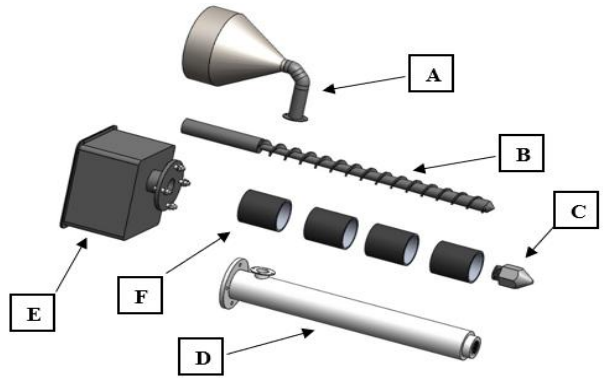

Figure 2 Exploded View of the 3D printer head

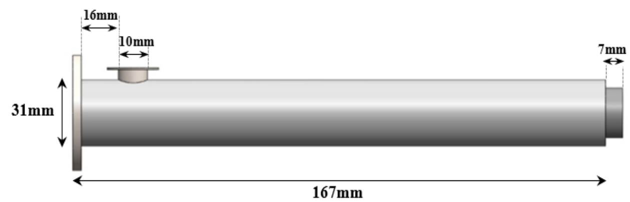

Figure 3 Side view of barrel

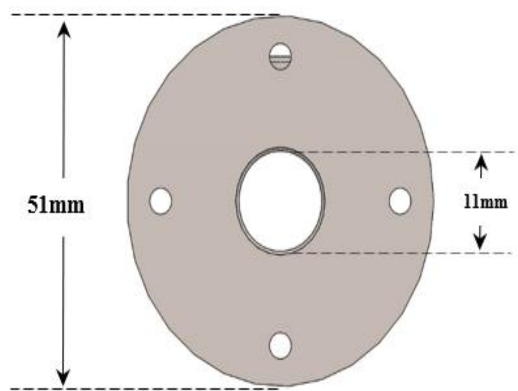

Figure 4 Cross-Sectional view of barrel

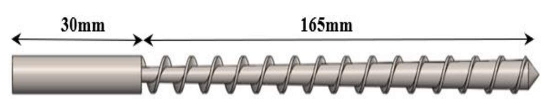

Figure 5 Side view of Extruder Screw

Material Consideration: For the filament, there are some engineering thermoplastic polymers that contain at least one further monomers in the main chain in addition to styrene (S) known as Styrenic copolymers (SCs). Styrene-acrylonitrile copolymer (SAN) and acrylonitrile-butadiene-styrene terpolymer (ABS) are well known styrenic copolymers. Apart from specialty styrenic copolymers based on other comonomers, blends of styrenic copolymers with other thermoplastics (styrenic copolymer blends) have also established themselves in the market. Blends of ABS with polycarbonate (PC) or polyamide (PA) are most prominent.

Table 1. Proposed Model Dimensions.

Parameters	Values
Screw length	165 mm
Screw dia	11 mm
Solid conveying length	2.5D= 27.5mm
Melt conveying length	6.25D= 68.75mm
Compression length	6.25D= 68.75mm
Pitch	8mm
Helix angle	17.7
Feed depth	4mm
Metering depth	1.25mm
Compression ratio	3:1
Flight width	3mm
Flight clearance	0.06mm

Styrene-acrylonitrile (SAN): SAN is an excellent transparent copolymer having up to 92% transfer of light, high tensile modulus, and surface properties such as gloss and reproduction micro textures in tools molding, better rigidity and hardness. As SAN is typically hard amorphous plastics, so has better dimensional accuracy and stability. In addition, with better rigidity and well impact resistance SAN is generally strong and resistant to scratches with good heat and strongly chemical resistance.

Acrylonitrile-butadiene-styrene (ABS): SAN have relatively low impact strength, which restrict its use for a lot of engineering applications. ABS is obtained by SAN modification by an elastomer, which combines the SAN advantages with the high impact resistance of an elastomer. Thus, ABS copolymers have excellent surface quality and dimensional stability. ABS has two phases, due to which it is generally opaque, in some cases it is translucent. ABS is preferred for covers and casings where high toughness, stiffness, strength with chemical resistance and thermal stability is expected altogether with high surface finishing.

PC+ABS (Bayblend T65): The blend (A blend is mixture of two or more polymers, which are microscopically dispersed or fully miscible. Most commercial blends comprise of two matrix resins whose compatibility may vary with one another) of PC+ABS combine an extraordinary mixture of mechanical, chemical and thermal properties. Polycarbonate gives the blend with excessive toughness at room temperature and good heat resistance. ABS also gives extraordinary stability against chemical resistance, stress cracking, and process-ability. The excellent property of PC+ABS is the low-temperature impact strength maintained to a lowest temperature of -30 °C which cannot be achieved by either ABS or PC individually This excellent property gives the important applications in the automotive industry. By applying the mechanical loads, the morphology given lead to deformation suppressed by shear deformation, even at lower temperatures, in place of crazing as is the case.

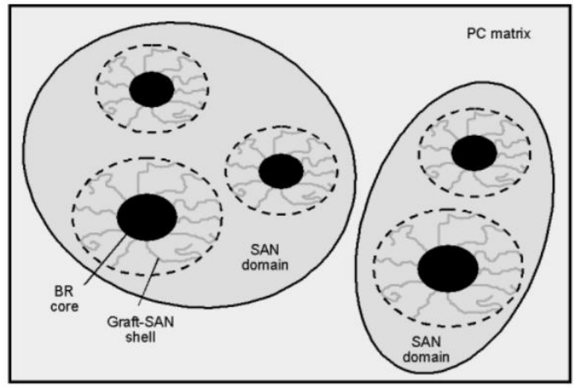

Figure 6 Morphology of PC+ABS Blend

Mechanical, thermal and rheological properties of SAN, general and high impact ABS. **Mathematical Model:** There are four main parts of plastic extruder, hopper, solid conveying, melting, melt conveying and the last one is dye (nozzle). Each portion is described separately below.

The plastic in the form of pellets or powder are poured down in the hopper manually and maintained 70% full volume of hopper. The hopper is connected with barrel of the plastic extruder with two 45 degree connecting elbows. The maximum mass of plastic pellets that can be poured into hopper is 300 to 400 grams, which is enough for small scale extrusion. The plastic pellets are transferred into the barrel of extruder usually by effect of gravity.

Solid conveying: In first part of extruder the flights of screw are kept deep as compared to other parts of extruder, which allows better flow of solid particles. Tangential and radial forces are applied on pellets due to collision between screw flights and solid particles which causes motion.

RESULTS AND DISCUSSION

Pressure profile is plotted in fig 7 against the screw rpm varying from zero to 100 using four different types of polymers. The blend of PC+ABS (T65) gives the highest pressure of 3.72 MPa and general-purpose ABS gives lowest pressure of 1.41 MPa at the rotational speed 100rpm of screw. In fig 8, the total flow rate output is plotted against the pressure developed inside the barrel using four different types of polymers, which shows that the general-purpose ABS gives high output flow rate at lowest pressure on the other hand T65 needs lowest pressure profile for the same output.

The size of die installed at the outlet of the extruder may vary according to application. In fig 9 two different dies (nozzles) are used of diameter 2mm and 3mm. Graph is plotted using these two diameter nozzles and four types of polymers. It is shown that using bigger diameter causes decrease in pressure being developed, which then results in more output flow rate. It can be seen in the graph that T65 material has the highest operating pressure with the 2mm diameter nozzle and with 3mm diameter nozzle, pressure is somewhat lower. While ABS has the lowest operating pressure with 3mm diameter nozzle.

It is evident in the graph that for better output flow rate, bigger diameter nozzle must be accommodated, but it must be 3mm or less than 3mm for better print quality and precision. Pressure developed along the axis of the extruder for different screw speed is described in fig 10 using ABS general purpose polymer, according to which there is minimal pressure produced in the solid conveying section and gives the maximum pressure in the compression section.

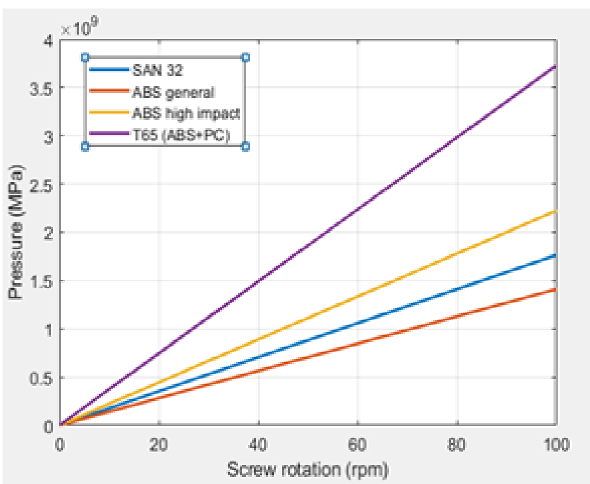

Figure 7. Pressure profile vs Screw rotations using four different polymer materials

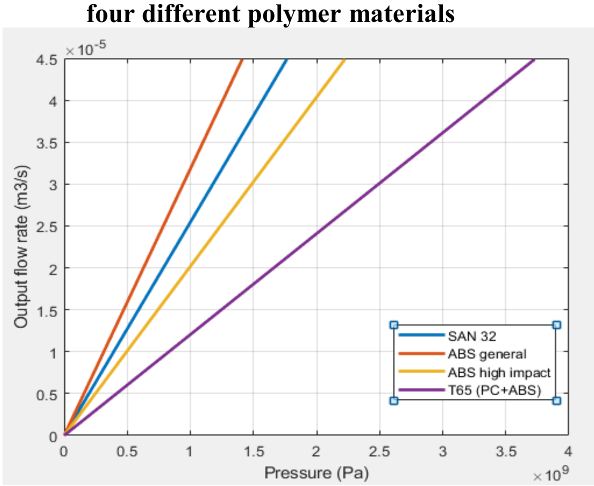

Figure 8 Pressure profile vs Output flow rate using four different polymer materials.

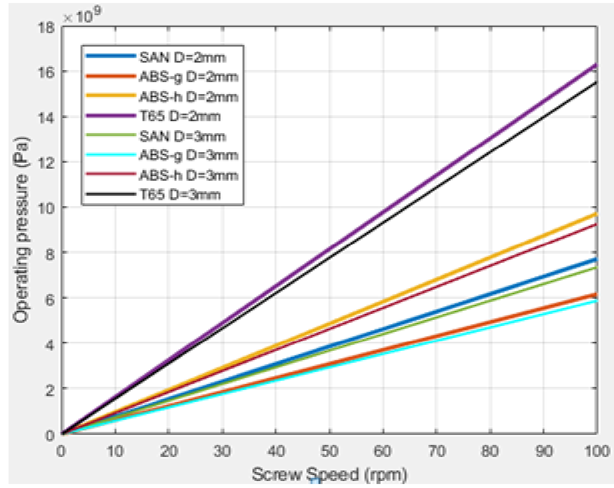

Figure 9. Effect of different nozzle sizes on operating pressure

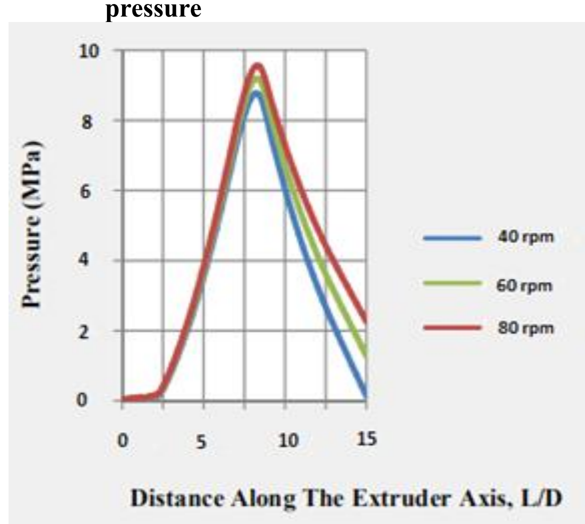

Figure 10 Pressure profile along the extruder axis

Conclusion: The current 3D printer with FDM technology has restricted its application because of its characteristic deficiency. It had limitation of single color and material printing which also resulted in low printing speeds. Printing of single color and material using extruder with a single nozzle needs extra time for filament replacement and cleaning of nozzle, which is complex and slow.

The proposed 3D printer head uses the basic extrusion process eliminating the need for switching filaments resulting in stoppage of operational performance. The proposed design is quite simple as a separate motor is not required because a gear is attached at the end of screw shaft which mashes with another gear in which machine shaft is connected. Hence, due to rotation of machine shaft, the screw rotates and material is deposited on the platform. Due to reduced weight and less bulky design, the printing speed also increases.

The proposed design of extrusion model provides a novel method for 3D printing with multi-color and multi-material advantages. Further investigation and experimental study are needed to further improve the design of extruder and optimization of the system extensions.

REFERENCES

Abilgaziyev, A., T. Kulzhan, N. Raissov, M.H. Ali, W.K. Match and N. Mir-Nasiri (2015). Design and development of multi-nozzle extrusion system for 3D printer. In *2015 International Conference on Informatics, Electronics & Vision (ICIEV)* (pp. 1-5). IEEE.

Arbaoui, Y., V. Laur, A. Maalouf and P. Queffelec (2015). 3D printing for microwave: Materials characterization and application in the field of absorbers. In *2015 IEEE MTT-S International Microwave Symposium* (pp. 1-3). IEEE.

Blandon, S., J.C. Amaya and A.J. Rojas (2015). Development of a 3D printer and a supervision system towards the improvement of physical properties and surface finish of the printed parts. In *2015 IEEE 2nd Colombian Conference on Automatic Control (CCAC)* (pp. 1-7). IEEE.

Drotman, D.T. (2015). *Design of a Screw Extruder for Additive Manufacturing* (Doctoral dissertation, UC San Diego).

He, Y., W. Quangang, L. Gang and L. Tingting (2017). Research on the control method of 3D printer based on FDM technology. In *2017 8th International Conference on Mechanical and Intelligent Manufacturing Technologies (ICMIMT)* (pp. 80-83). IEEE.

Junk, S. and C. Kuen (2016). Review of open source and freeware CAD systems for use with 3D-printing. *Procedia CIRP*, *50*, 430-435.

Oo, H.L., K.Z. Ye and Y.H. Linn (2018). Modeling and controlling of temperature in 3D printer (FDM). In *2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)* (pp. 1738-1742). IEEE.

Teterin, E., D. Zhuravlev and D. Berchuk (2016). Mobile extrusion machine for the production of composite filaments for 3D printing. In *2016 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)* (pp. 1-4). IEEE.