THE ASSESSMENT OF THE FILAMENT EXTRUDER EQUIPMENT FOR 3D PRINTING METHOD

Abdellatif Denine, Patrick Siegfried

Institute of Technology, MATE Hungarian University of Agriculture and Life Science, Páter Károly u. 1, 2100 Gödöllő, Hungary, patrick.siegfried@ism.de

ORIGINAL SCIENTIFIC PAPER

ISSN 2637-2150
e-ISSN 2637-2614
UDC 004.356.2 :658.286
DOI 10.7251/STED2201032D
COBISS.RS-ID 136254465

Paper Submited: 29.11.2021.
Paper Accepted: 04.04.2022.
Paper Published: 30.05.2022.
http://stedj-univerzitetpim.com

Corresponding Author:
Patrick Siegfried, Institute of Technology, MATE Hungarian University of Agriculture and Life Science, Páter Károly u. 1, 2100 Gödöllő, Hungary,patrick.siegfried@ism.de

ABSTRACT

The objective of this study is to allow a better understanding of the role of industry 4.0 technologies, especially filament extrusion technology in the reduction of costs, environmental impact, energy consumption, and the possibility to expand the range of printable materials. The study focuses on the desktop Filament Extruders available in the market now, where these machines are assessed and future possible modifications for these apparatuses are presented. The research leading to the publication of this study consists of a review of the existing literature, in addition, information from different extruders manufacturers' websites has been used. The study has demonstrated that the extrusion of material at home is still not an exact science, and the process ends up costing the user large sums of money over time. However, there are still limitations to the use of this technology such as the lack of standardized extrusion settings, the necessity of pre-drying the pellets, and the complexity of the extruder cleaning process after each use.

Keywords: Filament extruder, fused deposition modeling, industry 4.0, additive manufacturing.

JEL Code: L10

INTRODUCTION

New business models centered on customers and product customization are introduced by Industry 4.0. As a result, both the quantity of the service offered and the added value have risen. Industry 4.0 mainly focuses on automation, interoperability, and precision of the information, combined with underlying ethics conscious of the need for processes with low environmental impact (Haleem & Javaid, 2019).

Additive manufacturing (AM) has a major role in the industry 4.0 scenario (Xiong, 2020), which allows the fabrication of a three-dimensional item beginning from a computer-aided design (CAD) model.

Besides, AM permits considerable savings in terms of waste and logistic costs in comparison with conventional subtractive and formative manufacturing (Advanced Manufacturing Office, 2012), allowing printing 3D objects once the printing file has been acquired, wherever the 3D printer (3DP) is located.

AM is the process of joining materials to make objects from 3D model data generates, usually layer-upon-layer (ASTM International), which satisfies the increasing demand for product customization and enables the development of functional, flexible, and efficient parts and assemblies. Nonetheless, the most common additive manufacturing process for home and office environments is fused deposition modeling (FDM), which is characterized by a multitude of limitations (Pricci, de Tullio, & Percoco, 2021).

However, the evolution of these technologies is progressing at a rapid pace. 3D printers continue to get smaller and more accessible to consumers of all types, and since 3D printing at home is still not an exact science, waste becomes a large by-product of the process and ends up costing the user large sums of money over time. This problem can be solved through the process of material extrusion, as plastics are recyclable, this cycle could become the most sustainable way of making innovative items. For example, on the International Space Station (ISS) where the resources are limited, which also applies to the earth, an astronaut would be able to print a screwdriver on Wednesday, and then convert it into a box on Thursday.

There are currently products for sale that allow the extrusion of 3D filament in a home environment from 3D printed waste, but few support the whole manufacturing process of 3D filament and those that do are often expensive. Selling a machine that can reclaim 3D printed material, extrude it into reusable filament, and collect it through spooling at a cost-effective price point would benefit the user significantly and save them money over time, and would limit the amount of plastic waste being thrown out (Ertekin, et al., 2018).

Therefore, this study will focus on assessing the commercially available Filament Extruders and recommending useful solutions that will make the process of filament extrusion in an in-house environment more efficient, enabling the use of a wider range of materials and more accessible for the average consumer.

LITERATURE REVIEW AND HYPOTHESIS DEVLOPMENT

The Fused Deposition Modelling was invented and patented in 1989 by Scott Crimp who had created the company Stratasys a little after, which commercialized the first 3D FDM printers (Minnesota, United States of America Brevet n° 5,121,329, 1992). The concept of the FDM manufacturing process consists of melting raw material and forming it to create the desired shape. **See Figure 1. (b)**

The filament is the main material utilized in the FDM-based 3D printing method. Polymer filament is divided into two types corresponding to its composition, pure polymer filament and composite filament (Wang, Jiang, Zhou, Gou, & Hui, 2017). Generally, the filament is made of pure polymers with a low melting point. Sometimes, the strength of pure polymer needs to be boosted by additive materials such as glass fibers, carbon nanotubes, microcrystalline cellulose, and others. Therefore, polymer composites have been developed by numerous researchers and industries as 3D printing filament material through the combination of the matrix and improving the components to attain systems with structural properties and practical advantages which cannot be accomplished by just any constituent (Kristiawan, Imaduddin, Ariawan, Ubaidillah, & Arifin, 2021).

Usually, the commercial filament is made in large facilities with machines known as filament extruders, where granulated material pellets are melted and then fed through a nozzle forming 3D printable filaments. Many kits are used during the extrusion process to ensure the filament comes out properly. Professional filament extruders used in the mass production of spools that companies use are expensive and take up a lot of space. However, in recent years an increasing number of consumers have turned to new manufacturers looking to recycle waste material and save money by making their filament. There are currently products for sale as kits and pre-assembled machines that allow the extrusion of 3D filament in a home environment from 3D printed waste.

FFF (fused filament fabrication) 3D printing' pure polymer filament can be made through the process of extruding pellets or raw materials from polymers (like PLA, ABS, PP, and others). This procedure is carried out using extruders that shove or force the material through holes in the die to get the product as an extrudate (Rauwendaal, Polymer Extrusion 5th Edition, 2014). **See Figure 1. (a)**

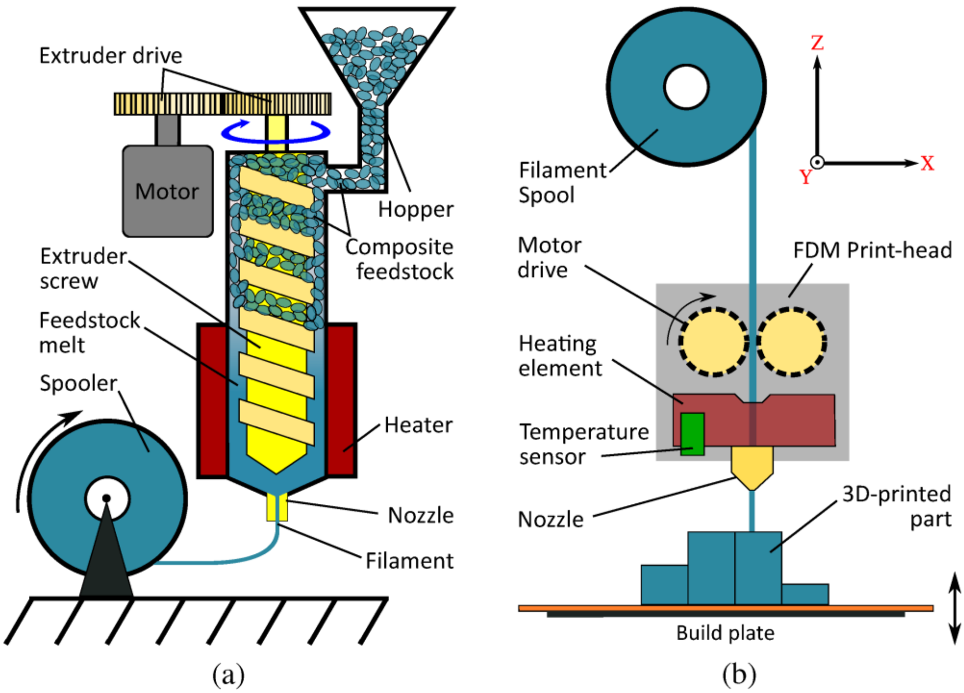

Figure 1. (a) A schematic depiction of the filament extrusion process. (b) The FDM printing process *(Khatri, et al., 2018).*

Tables 1, 2, and 3 compare the major desktop extrusion players in the market (O'Connell & Obudho, 2021). The assessment is based on key characteristics necessary for a proper extrusion, such as extrusion rate, supporting materials, extruder's maximum temperature, and so on. This is proposed as a technical comparison tool, which will include a feature overview of each brand.

Table 1. Comparison of commercially available extruders (Filastruder, 2021) (Felfil, 2021) (KICKSTARTER, 2021)

	Filastruder	**Felfil Evo Assembled**	**OmniDynamics**
Maximum extruder's temperature (° C)	260	250	250
Extrusion rate (kg/h)	0.2	0.2	0.27
Filament size (mm)	1.75 – 3.00	1.75 – 2.85	1.75 – 2.85 – 3.00
Extrusion accuracy (mm)	+/- 0.05	+/- 0.07	+/- 0.1
Filament diameter control	None	None	None
Filament cooling	Build-in	Not available	Not available
Type of filament cooling	Air	None	None
Hopper capacity (cm^3)	1000	1000	1000
Heat zone(s)	1	1	1
Heat zone control	No/Does not apply	No/Does not apply	No/Does not apply
Mixing zone	No	No	No
Winding system	Separate	Not available	Separate
Operating voltage	110-240V, 50/60Hz	110V – 230V	115-220V
Power consumption (Watts)	60	80	Not available
Dimensions w x d x h (cm)	53.34×15.24×15.24	47×38×12	16.5×28.5×16.5
Cost ($)	300.00	840.13	1484.05

Table 2. Comparison of commercially available extruders (Filabot, 2021) (ReDeTec, 2021) (Filafab, 2021)

	Protocycler+	**Filabot EX 2**	**Filafab PRO 100 EX**
Maximum extruder's temperature (°C)	250	350	250
Extrusion rate (kg/h)	0.5	0.91	0.25
Filament size (mm)	3.00	1.75 - 2.85	1.75 – 2.85
Extrusion accuracy (mm)	+/- 0.05	+/- 0.05	+/- 0.02
Filament diameter control	Automatic	Manual	Temperature control available
Filament cooling	Build it	Included in setup	Separate
Type of filament cooling	Air	Air	Air
Hopper capacity (ml)	Expandable	426.1	350
Heat zone(s)	4	1	1
Heat zone control	No/Does not apply	Yes	No/Does not apply
Mixing zone	No	Yes	No
Winding system	Build-in	Included in setup	Separate
Operating voltage	120 V	110 V, 220 V - 50 to 60Hz	120 – 220 V
Power consumption (Watts)	90-120	500	350
Dimensions w x d x h (cm)	15 x 14 x 9	45.75 x 17.78 x 22.86	16.4 x 49 x 24
Cost ($)	3,499.99	2,812.00	1,607.27

Table 3. Comparison of commercially available extruders (Noztek, 2021) (Wellzoom, 2021) (3devo, 2021)

	Noztek	**Wellzoom B2**	**3devo 350 Precision**
Maximum extruder's temperature (° C)	400+ (600, 750 on request)	300	350
Extrusion rate (kg/h)	0.5	0.1	0.7
Filament size (mm)	1.75 – 3.00	1.75 - 3.00	0.50 – 3.00
Extrusion accuracy (mm)	+/- 0.04	+/- 0.05	+/- 0.043
Filament diameter control	Manual	None	Automatic
Filament cooling	Included in setup	Separate	Built-in dual fan system
Type of filament cooling	Water	None	Air
Hopper capacity (ml)	1000	400	2000
Heat zone(s)	3	1	4
Heat zone control	Yes	No / Does not apply	Yes
Mixing zone	No	No	No
Winding system	Included in setup	None	Built-in
Operating voltage	110V, 220V	220V, 50Hz or 110V 50Hz	110 - 230 V, 50 - 60 Hz
Power consumption (Watts)	464	120	Not available
Dimensions w x d x h (cm)	135 × 40 × 40	20 x 5.52 x 10	50.6 × 21.7 × 61.5
Cost ($)	18,584.04	588.00	6008.95

From the tables above we can remark that the available extruders present various limitations such as the limited extruder's maximum temperature, the extrusion rate, the filament's diameter accuracy, and so on. All these problems will be discussed in detail in the part Results and discussions.

RESEARCH METHODOLOGY

The research leading to the publication of this study consists of a review of some literature about industry 4.0, additive manufacturing, fused deposition modeling, and filament extrusion. In addition, information from different extruders manufacturers' websites has been used. Besides, research databases such as Google Scholar, Research Gate, and Science Direct have been used to get journal articles and book sections related to the current work.

RESULTS AND DISCUSSION

Overall, the tables show that the existing extruders have numerous weaknesses that make them inefficient. First off, these setups require the operator to have a piece of prior knowledge about materials characteristics (e.g., melting points) to set the right configuration for each material. Secondly, the maximum temperature reached by the extruder determines the materials that the device can accommodate. More the temperature is high more materials can be extruded (O'Connell & Obudho, 2021). So, here we can see that the maximum extruder's temperature is 400°C in the best case, which is not sufficient for extruding all polymers, for example, polysulfone and vespel. Most extruders accessible to the public now can only use a limited number of materials, for instance, Polyethylene Terephthalate (PET), Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), and Nylon. Thirdly, as we can see from the table only the Filabot EX2 extruder has a mixing zone. The existence of the last is crucial to make composite filament (polymer reinforced with additive materials). In addition, the extrusion rate is quite slow for most of the apparatuses, especially Wellzoom B2, which has the lowest extrusion speed of 0.1kg per hour. The latter can be related to the power consumption of these devices which is on average 280 watts, which means that the user ends up spending a lot on electricity. Likewise, some extruders do not provide filament diameter control and a cooling system that will lead to a nonuniform filament thickness. A problem like this will decrease the quality of the filament and make it unsuitable for printing high-quality pieces. Furthermore, apart from the Do-It-Yourself (DIY) apparatuses such as Filastruder, the cost of these devices is extremely high for the average user. Finally, the volume of the hopper is fairly small, which makes it obligatory for the user to refill the hopper with pellets regularly till the end of the extrusion.

CONCLUSIONS

The study has demonstrated that the extrusion of material at home is still not an exact science, and the process and ends up costing the user large sums of money over time. Whilst, as it has been stated that Industry 4.0 principles look for low environmental impact and effective manufacturing processes. Therefore, more research must be done in this scope to upgrade the Filament Extruder Equipment, so that it meets the consumer's current needs. Three essential solutions that must be accomplished to make these devices more efficient are: Increasing the extruder's maximum temperature, and the number of heating zones; Enlarging the hopper volume; Incorporating more mixing zones in the extruder.

The accomplishment of these attributes will lead to a Filament Extruder Equipment, with a high extrusion rate and a longer list of material that can be processed, as well as a higher autonomy. The findings of this study can be useful in the field of mechanical engineering, aerospace engineering, art and jewelry, and medicine.

LIMITATION AND STUDY FORWAR

This study did not cover some other weaknesses such as selecting the starting point temperature for the extrusion, which can be very detrimental and time-consuming. On one hand, if the chosen temperature is lower than the melting point of the used polymer, there might be unmelted particles at the outputs, which in the worst case will cause the nozzle to pop or block the machine completely. On the other hand, if the temperature is too high, then the resulting filament will be too soft and cannot be used.

Another problem is that many polymers are hygroscopic, which means they can absorb moisture inside their structure, this can cause problems during the filament extrusion by disrupting the flow and possibly causing bubbles. That is why polymers should often be pre-dried (Rauwendaal, Polymer Extrusion 5th Edition, 2014). Furthermore, all the polymers must be purged from the extruder before turning it off, since the screw might be completely stuck, and the machine might not be able to switch on anymore.

All in all, standardized extrusion settings and extruder cleaning process must be made in order to achieve a highly efficient and simple-to-use extruder.

LITERATURE

3devo. (2021). *Composer 350.* Retrieved November 18, 2021, from 3devo: https://3devo.com/product/composer-350/

Advanced Manufacturing Office. (2012). *Additive Manufacturing: Persuing the Promise.* Washington: U.S. Department of Energy.

ASTM International. (n.d.). Standard Terminology for Additive Manufacturing Technologies. *F2792 − 12a* (pp. 1-3). West Conshohocken: ASTM International.

Crump, S. S. (1992, June 9). *Minnesota, United States of America Patent No. 5,121,329.*

Ertekin, Y., Chiou, R., Nicoleta, I., Leibowitz, J. S., Armstrong, J., &

Laage, N. (2018). Interdisciplinary Senior Design Project to Develop a Teaching Tool: Filament Extruder. *2018 ASEE Annual Conference & Exposition Proceedings*. doi: 10.18260/1-2--30701

Felfil. (2021). *Felfil Evo*. Retrieved November 18, 2021, from Felfil: https://felfil.com/felfilevo-filament-extruder/?v=5ea34fa833a1

Filabot. (2021). *Filabot EX6 extruder setup*. Retrieved November 18, 2021, from Filabot: https://www.filabot.com/products/ex6-bundle

Filafab. (2021). *FilaFab PRO 100 EX*. Retrieved November 18, 2021, from Filafab: http://d3dinnovations.com/filafab/product/filafab-ex-100/

Filastruder. (2021). *Filastruder*. Retrieved November 18, 2021, from Filastruder: https://www.filastruder.com/collections/filastruders-accessories/products/filastruder-kit?variant=323882043

Haleem, A., & Javaid, M. (2019). Additive manufacturing applications in industry 4.0: a review. *Journal of Industrial Integration and Management, 04*(04), 1930001.

Khatri, B., Lappe, K., Habedank, M., Mueller, T., Megnin, C., & Hanemann, T. (2018). Fused Deposition Modeling of ABS-Barium Titanate Composites: A simple route towards tailored dielectric devices. *Polymers, 10*(6), 666.

KICKSTARTER. (2021). *Strooder, First Truly Consumer 3D Printing Filament Extruder*. Retrieved November 18, 2021, from KICKSTARTER: https://www.kickstarter.com/projects/omnidynamics/strooder-first-truly-consumer-3d-printing-filament/description

Kristiawan, R., Imaduddin, F., Ariawan, D., Ubaidillah, & Arifin, Z. (2021). A review on the fused deposition modeling (FDM) 3D printing: Filament processing, materials, and printing parameters. *Open Engineering*, *11*(1), 639-649. doi: 10.1515/eng-2021-0063

Noztek. (2021). *Noztek Pro Filament Extruder*. Retrieved November 18, 2021, from Noztek: https://www.noztek.com/product/noztek-pro/

O'Connell, J., & Obudho, B. (2021). *Best Filament Extruders of 2021*. Retrieved October 24, 2021, from All3DP: https://all3dp.com/2/best-filament-extruder-maker-diy-buy/

Pricci, A., de Tullio, M. D., & Percoco, G. (2021). Analytical and Numerical Models of Thermoplastics: A Review Aimed to Pellet Extrusion-Based Additive Manufacturing. *Polymers, 13*(18), 3160.

Rauwendaal, C. (2014). *Polymer Extrusion 5th Edition.* Munich: Carl Hanser Verlag GmbH & Co. KG.

ReDeTec. (2021). *ProtoCycler+*. Retrieved November 18, 2021, from ReDeTec: https://redetec.com/products/protocycler?variant=39805373743152

Wang, X., Jiang, M., Zhou, Z., Gou, J., & Hui, D. (2017). 3D printing of polymer matrix composites: A review and prospective. *Composites Part B: Engineering, 110*, 442-458. https://doi.org/10.1016/j.compositesb.2016.11.034

Wellzoom. (2021). *Wellzoom desktop filament extruder B*. Retrieved November 18, 2021, from Wellzoom: http://wellzoomextruder.com/product/wellzoom-desktop-filament-extruder-b/

Xiong, S. (2020). Materials, Application Status and Development Trends of Additive Manufacturing Technology. Materials Transactions, 61(7), 1191-1199. https://doi.org/10.2320/matertrans.MT-M2020023