A Review on the Effect of Extrusion Parameter on 3D Printing Filament Diameter

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Abstract. Over the years, the extrusion technique has captured the attention of polymer industries by meeting the demand for polymer processing and fabrication of final products. Extrusion is a continuous process, and it has a lot of potential in the increasing polymer sector, especially in the three-dimensional (3D) printing sector. 3D printing is popular because the feedstock filament form is accessible and produce able. The properties of the filament used influence the printed part qualities regardless of the FDM parameters. This study provides information on how extrusion parameters affect the diameter of extruded filaments. This study reviews previous studies on the effect of varied extrusion settings on filament diameter. The review will serve as a resource for researchers in the 3D printing sector to fabricate their filaments for 3D printing. Overall, this paper will provide solutions to overcome issues in obtaining optimal filament diameters for future research projects.

Keywords: Extruder · Extrusion · Filament · Barrel Temperature · Extrusion Speed · Diameter

1 Introduction

One of the most well-known polymer processing methods is extrusion. The extrusion method applies to melt blending, homogenizing of material, forming finished goods, and pelletizing polymeric melt [1–6]. Single-screw extruders and twin-screw extruders are two kinds of extruders available in polymer processing.

The major components of the extruder are the heating barrel, screw profile along the barrel, motor for screw rotation, and die for the shaping of extrudates [7, 8]. There are

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three sections in the extruder's flow channel of the barrel: the feed zone, the transition zone, and the metering zone. The feed material enters the feed zone from the hopper, and the melted polymer is conveyed to the transition zone through pressure and shear generated within the barrel. Here is where the mixing and intermixing occur. Then, the molten polymer flows towards the die and out of the nozzle [9, 10]. The extruded filament solidified through a water bath or a cooling fan [11].

The source material for the 3D printer is filament form. Many kinds of thermoplastic filament materials are available in the 3D printing industry [12, 13]. Regardless of the material availability, the research interest in producing new filament material is rising to fabricate diverse 3D printing feedstock materials. Filament fabrication covers a range of materials, such as thermoplastic elastomer, composite, blend, and recycled filament. Each filament fabrication has different processing requirements. They standardised the filament diameter, with typical sizes of 1.75 mm, 2.85 mm, and 3 mm [14]. The diameter and quality of the filament are affected by extrusion processing factors, such as extrusion temperature, extrusion speed, nozzle diameter, spindle speed, and cooling conditions. Extrusion parameters are crucial for forming filaments with consistent roundness and dimensional precision while manufacturing filaments.

2 Effect of Extrusion Parameter on Filament Properties

Extrusion parameters are crucial for forming filaments with consistent roundness and dimensional precision while manufacturing filaments. The dimensional accuracy affects the quality of the filament. Diameter tolerance refers to the variance in the filament dimension during extrusion. To achieve a uniform diameter and continuous filament with optimum form, 3D printer filaments are typically generated using a single screw extruder, and adjusting the filament extruder settings is required. The quality of the filament influences the properties of 3D-printed components [14]. This section discusses the influence of filament extruder settings on filament diameter. Table 1 presents the summary of the research works for filament diameter.

Nassar et al. (2019) [11] performed filament fabrication using high-density polyethylene (HDPE) by varying extrusion speed and cooling method while maintaining constant extrusion temperature. Table 2 represents the reading of filament diameter under different extrusion parameters. The researcher focused on the cooling effect of filament to ensure the roundness of filament with a consistent diameter. Based on the results, a higher extrusion rate did not melt feed materials completely to form uniform dimensions. The solidification happens at a faster pace by using a cold air gun. Thus, these studies reveal the filament does not have sufficient time to extend to achieve the ideal diameter under tension between the nozzle and the spooler. At a lower extrusion rate, the material has adequate time to melt to the desired stage, and the melt flow rate is in a controlled condition. Cooling of filament using a water bath allows the filament to extend further upon tension and form a smaller-diameter filament. A slower extrusion rate and solidification via a cold air gun produced the preferred filament size [11].

Mirón et al. (2017) [15] conducted research work to manufacture filament for a 3D printer with a diameter of 2.85mm. They implemented an extrusion temperature range of 175 °C to 195 °C for processing polylactic acid (PLA) pellets into filaments

Table 1. A summary type of extruder and processing parameters

No	Author	Extruder Type	Input Parameter	Variable	Material	Findings
1	Nassar et al., (2019) [11]	Filament extruder	• Extrusion speed (rpm) • Cooling method	• 18,22 • Cold air gun, water bath	High density polyethylene	Filament fabrication under slower extrusion speed with a hot air gun cooling method is effective in producing filament in the required range
2	Mirón et al., (2017) [15]	Filabot EX2 extruder	• Extrusion temperature (°C)	• 165,1700,175,180,185,190	Polylactic acid	Larger diameter filament fabricated under lower extrusion temperature and vice versa. The optimum extrusion temperature for PLA is between 175 °C-180 °C
3	Herianto et al., (2020) [16]	Single screw extruder	• Spooler speed (rpm) • Extrusion speed (rpm) • Extrusion temperature (°C)	• 2,4 • 40,50 • 180,190,200	Recycled polypropylene	The spooler speed and extrusion speed need to work parallelly to achieve consistent filament diameter
4	Kuo et al., (2021) [17]	Wellzoom desktop extruder	• Extrusion temperature (°C) • Extrusion speed (rpm) • Cooling distance (mm)	• 182,184,186 • 480,490,500 • 52.5,55,57.5	Recycled Polylactic acid	Under higher extrusion temperatures and faster speed, the structural stability of the filament reduces which causes a smaller diameter of the filament
5	Liu et al., (2018) [18]	Wellzoom desktop extruder	• Extrusion temperature (°C) • Extrusion speed (rpm)	• 185,190,195,200 • 2,3,4,5,6	Polylactic acid	A larger diameter of filament fabricated due to die swell behaviour under higher temperatures with faster extrusion speed

Table 2. Error! No text of specified style in document..Filament diameter under different extrusion parameters.

Run	Extrusion temperature (°C)	Extrusion speed (rpm)	Cooling method	Filament diameter (mm)
1	180	22	Cold air gun	1.81 ± 0.02
2	180	22	Water bath	1.68 ± 0.02
3	180	18	Cold air gun	1.74 ± 0.02
4	180	18	Water bath	1.65 ± 0.02

under automatic extrusion speed. Extruding at a lower temperature of 165 °C produces filament with a high diameter. In addition, a smaller diameter with a blister on the surface of filaments was obtained at a high extrusion temperature of 185 °C to 190 °C. Their findings highlight issues with manufacturing filaments under various temperatures, and troubleshooting methods are shown in Table 3 below. Based on their studies, the ideal extrusion temperature is 175 °C-180 °C for the extrusion of PLA. However, further analysis regarding the effect of extrusion speed and observations on the roundness of the filament is required to understand the impact of extrusion speed. Since the extrusion speed of the screw profile along the barrel affects torque and shear, that influences transition behaviour and flow output.

Table 3. Extrusion parameters and troubleshooting methods

Extrusion temperature (°C)	Extrusion speed	Troubleshooting	Solutions
165	Very slow	High diameter	Increase temperature
170	Slow	High diameter	Increase temperature
175	Good	-	-
180	Good	-	-
185	Fast	Filament with blister and small diameter	Decrease temperature
190	Too fast	Filament with blister and small diameter	Decrease temperature

Another research by Herianto et al., (2020) [16] focused on optimizing extrusion parameters such as spooler speed, extrusion rate, and temperature to achieve a consistent filament diameter using recycled polypropylene. The target diameter of the filament was 1.75mm with 0.05mm tolerance. As per the findings, they obtained the desired filament diameter with an extrusion temperature of 200 °C, 4 rpm spooler speed, and extrusion

Table 4. Filaments diameter obtained under various extrusion temperatures and screw speeds

Screw speed (rpm)	Extrusion temperature (°C)			
	185	190	195	200
2	1.756	1.680	1.620	1.448
3	1.760	1.721	1.680	1.575
4	-	1.791	1.727	1.665
5	-	1.831	1.810	1.747
6	-	1.946	1.888	1.857

speed at 40 rpm. Under a slower spooler speed of 2 rpm and an extrusion speed of 40 rpm, the diameter of the filament is larger. The faster setting for the spooler and screw speed causes the filament to have a smaller diameter. According to the Analysis of Variance (ANOVA) result, the spooler and extrusion speed highly influence the filament diameter. They found that the filaments produced have rougher textures. The rougher filament produces printed parts with irregular surfaces. Thus, the researchers are required to focus on enhancing the filament quality, roundness and smoothness to achieve good printing quality.

Kuo et al. (2021) [17] conducted research to fabricate filaments made from PLA by manipulating extrusion variables, such as extrusion temperature, extrusion speed, and cooling distance between the nozzle and the spooler. The findings show that a rise in barrel temperature from 176 °C to 182 °C leads to an increase in filament diameter. Extrusion temperature at 182 °C is optimal to achieve a filament diameter of 1.75mm. Further temperature rise above the ideal temperature reduces the filament diameter. The filament diameter gets smaller with faster extrusion speed. Extrusion speed at 490 mm/min produced filament with 1.7 mm with smaller standard deviations, while 480 mm/min produced filament with 1.65 mm with minimal variations. Solidification is necessary for fabricating filament. A cooling distance of 55 mm fabricates a filament with the target diameter. The research highlighted that filament size accuracy is highly affected by extrusion temperature compared to other parameters. The variations in filament diameter reflect how minor changes in variables can affect the output filaments. In the future, the researchers should perform melt flow index testing to understand rheological behaviour, which reveals the structural stability of filament in maintaining the desired shape and diameter in filament fabrication.

Liu et al. 2018 [18] studied the effect of filament extruder parameters that affect the diameter of the filament. Table 3 shows the filament diameter achieved under various extrusion temperatures and screw speeds. The researcher reported that, as temperature increases, the diameter decreases. This phenomenon shows melting viscosity behaviour. Higher extrusion temperature reduces die swelling and improves the volume flow rate. However, a rise in extrusion rate shows an increasing trend in filament diameter because of the high volume of material extruded. The data revealed that, with an extrusion speed of 5 rpm and 200 °C, a satisfied filament diameter of 1.75 mm was produced. However, the research study could have added the study factor of spooler speed in filament fabrication.

The spooler speed matching the extrusion speed is necessary to produce a filament with a constant diameter. An imbalanced speed between the spooler and screw will cause higher tension, which causes variations in filament diameter.

3 Conclusion

In summary, the filament diameter relies on multiple settings of the filament extruder. The primary motive is to achieve a consistent filament diameter by optimizing the extruder's parameters and ensuring the prepared filament has good printing ability and denotes good properties in printed parts. Based on the findings above, the temperature setting depends on the material melting point, glass transition temperature, and degradation temperature, and it highly affects the material rheological behaviour. Besides, the speed of the spooler has a high effect on filament diameter as it determines the output of material flow, which eventually influences the filament size. The winding process causes tension in the filament. Thus, speed optimization is necessary. The process needed to be smooth to avoid the coiling effect and stretching of the filament. On the last note, cooling assists in solidifying a filament into the desired shape and size. Less cooling affects the filament quality, where the roundness is inconsistent, and the size will be non-uniform.

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