EFFECTS OF EXTRUSION PARAMETERS ON FILAMENT QUALITY AND MECHANICAL PROPERTIES OF 3D PRINTED PC/ABS COMPONENTS

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Material extrusion (MEX) is an additivive manufacturing technology (AM), which includes technique such as Fused deposition modeling (FDM) as well as similar Fused filament fabrication (FFF). The technology relies on thermoplastic materials with tailored mechanical properties to meet specific application requirements. This study investigates the extrusion and mechanical performance of polycarbonate (PC), acrylonitrile butadiene styrene (ABS), and their blends to optimize material properties for FDM/FFF applications. Mechanical characterization, including hardness, tensile, and flexural testing, reveals that PC demonstrates superior thermal stability and mechanical strength, while ABS offers enhanced processability and flexibility. The PC/ABS blend demonstrates a balanced combination of these attributes, achieving improved mechanical performance compared to ABS while maintaining better printability than pure PC. These findings provide valuable insights into the optimization of polymer blends for AM, enabling the development of high-performance materials for engineering applications requiring enhanced mechanical properties and printability.

KEYWORDS

Blend, Extrusion, FDM/FFF, Polycarbonate (PC), Acrylonitrile butadiene styrene (ABS)

1 INTRODUCTION

Additive Manufacturing (AM) has revolutionized modern manufacturing by enabling the layer-by-layer fabrication of complex geometries with high efficiency and minimal material waste. Material extrusion (MEX) is recognized as a fundamental AM technology, with Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) being the most prominent implementations. This process has gained significant attention due to its cost-effectiveness, ease of operation, and compatibility with a wide range of thermoplastic materials, making a critical component in the advancement of AM [Shahrubudin 2019; Samykano 2019; Reich 2019; Vidakis 2022; Zur 2020]. Among the various materials used in MEX, acrylonitrile butadiene styrene (ABS) and polycarbonate (PC) are particularly prominent due to their excellent mechanical properties and versatility. ABS is widely known for ease of processing, good mechanical strength, and cost-effectiveness, making it a go-to material for general-purpose applications. However, the limited thermal stability and impact resistance can restrict performance in certain high-demand environments [Kuram 2016; Samykano 2019]. In contrast, PC is a high-performance thermoplastic that stands out for superior thermal stability, high impact resistance, and excellent dimensional stability, which makes the ideal for demanding applications, such as aerospace, automotive, and electronics [Allen 2022; Mishra 2022; Bendler 1999]. Despite these advantages, PC exhibits certain drawbacks in FDM/FFF processing, including higher printing temperatures, increased susceptibility to warping, and reduced ease of processing compared to ABS. These challenges limit the applicability in desktop-scale 3D printing and complicate the fabrication process.

To overcome the limitations of these individual materials, PC/ABS blends have gained popularity in FDM/FFF applications. By combining the mechanical strength and ease of processing of ABS with the thermal stability and impact resistance of PC, these blends offer an optimal balance of printability, durability, and performance. The resulting PC/ABS blends have become increasingly valuable in industrial and functional prototyping, where both mechanical properties and ease of fabrication are required [Saharudin 2021; Kozior 2024; Verma 2023; Liu 2023]. Previous studies have explored the properties and applications of PC/ABS blends in FDM/FFF, there remains a lack of comprehensive research on optimizing extrusion and printing parameters to achieve filament quality comparable to commercial products. This esearch investigates the relationship between process parameters and material performance to enhance the printability and mechanical strength of PC/ABS blends. By addressing these challenges, the study provides insights into the production of high-quality PC/ABS filaments for FDM/FFF applications, contributing to the advancement of material extrusion-based additive manufacturing.

2 MATERIAL AND METHOD

2.1 Filament preparation

Polycarbonate (PC) and acrylonitrile butadiene styrene (ABS) were procured in pellet form under the commercial names Infino SC-1100UR and MAGNUM 3904 Smooth, respectively, both supplied by Resinex. The detailed material specifications are presented in Tab. 1.

Properties	Unit	PC	ABS
Density	g/cm^3	1.2	1.05
Melt Mass – Flow rate (MFR)	g/10 min	12	4.7
Molding Shrinkage	%	0.5 – 0.7	0.4 – 0.7
Vicat temperature	°C	146	97
Deflection Temperature Under Load	°C	125	97

Table 1. The properties of raw materials

Prior to processing, the polymer pellets were dried at 90 °C for 12 hours, following the manufacturer's guidelines to remove residual moisture. Subsequently, the pellets were extruded into 1.75 mm - diameter filament using a 3D Evo Composer 350 (3D Evo B.V., Utrecht, The Netherlands), a single-screw filament

extruder. In this study, three different filaments were utilized, each with distinct compositions: pure PC, pure ABS, and a PC/ABS blend with a 50/50 mass ratio, referred to as PC/ABS.
In this study, extrusion nozzles with two different diameters, 2 mm and 4 mm, were utilized to examine the effect of nozzle size on the quality of the extruded filament. The resulting filament was subsequently used in the FDM 3D printing process to manufacture test specimens.
The extrusion parameters, including heating zone temperatures, screw speed, and cooling fan speed, were optimized to ensure a stable filament diameter and high-quality output for 3D printing. The extruder featured four heat zones: Zone 1 (near the nozzle) controlled melt and flow properties, Zone 2 provided thermal support, Zone 3 stabilized material flow, and Zone 4 (near the hopper) prevented pre-melting. These specific extrusion parameters are detailed in Tab. 2.

Material	Heating Zone temperature (°C)				Fan Speed (%)
	T4	T3	T2	T1	
PC/ABS	230	270	270	270	50
	210	250	250	250	50
	200	230	230	230	20
PC	220	250	250	250	0-10
ABS	200	220	220	220	20-30

Table 2. Parameters used in extruding of the filament

2.2 Sample preparation

The samples for mechanical testing, specifically for tensile and three-point bending tests, were 3D printed in accordance with the EN ISO 527-2 and EN ISO 178 standards. The specific dimensions of the samples are provided in Fig. 1. The specimens were designed using SolidWorks and subsequently sliced using Bambu Studio, with the printing parameters outlined in Tab. 3.

Process Parameter	PC	ABS	PC/ ABS	PC-C	ABS -C
Nozzle temperature (°C)	270	260	265	270	240
Build plate temperature (°C)	110	100	110	110	100
Chamber temperature (°C)	60	60	60	60	60
Infill (%)	100	100	100	100	100
Layer thickness (mm)	0.2	0.2	0.2	0.2	0.2
Printing speed (mm/s)	60	40	40	60	40
Infill direction (º)	45	45	45	45	45

Table 3. Parameters used in 3D printing samples

In this study, three types of filaments were custom fabricated: PC, ABS, and a PC/ABS blend. Additionally, two comercially produced, PC-C (supplied by Prusa) and ABS-C (provided by Fillamentum), were used as well.

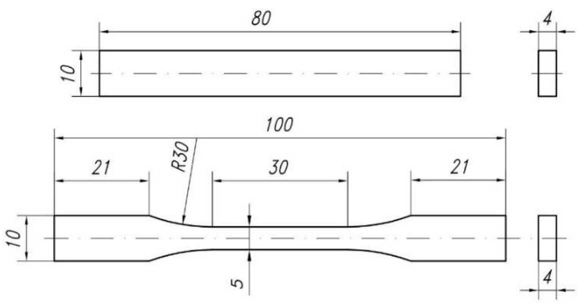

Figure 1. The dimensions of the tensile and 3-point bending samples

2.3 Mechanical test preparation

The mechanical properties of samples were determined in accordance with the EN ISO 527-2 and EN ISO 178 standards. A Universal Testing Machine (UTM) (Zwick/Roell, Germany), equipped with a 10 kN load cell, was used to evaluate the mechanical properties. Tensile and three point bending tests were conducted at a constant crosshead speed of 10 mm/min, with three specimens of each filament type tested at an ambient temperature of 23 ± 2 °C.
The hardness of the samples was evaluated using the Shore D method, according to ASTM D2240, employing a DIGI-Test II hardness tester (Bareiss, Oberdischingen, Germany). To ensure the accuracy and reliability of the results, five individual measurements were taken at different locations on each sample. The average value of these measurements was then used to evaluate the overall hardness of the sample.

3 RESULT AND DISCUSSION

3.1 Factors influencing filament quality in the extrusion process

The quality of extruded filament is influenced by multiple parameters. Key factors affecting filament quality include extrusion temperature, screw speed, cooling rate, nozzle diameter, and material composition.

3.1.1 Effect of extrusion temperature on the quality of filament

The extrusion temperature significantly influenced the morphological characteristics of the PC/ABS filament. The filament extruded at 270 °C exhibited a yellowish discoloration (See Fig. 2a), indicative of thermal degradation due to polycarbonate (PC) decomposition at elevated temperatures [Allen 2022]. This degradation led to structural inconsistencies, rendering the material unsuitable for 3D printing applications.

Figure 2a. Filament morphology under 270° C extrusion

Reducing the temperature to 250 °C resulted in a transition to a white coloration (See Fig. 2b), however, diameter irregularities persisted due to incomplete homogenization of the polymer blend and non-uniform flow dynamics, adversely affecting extrusion stability.

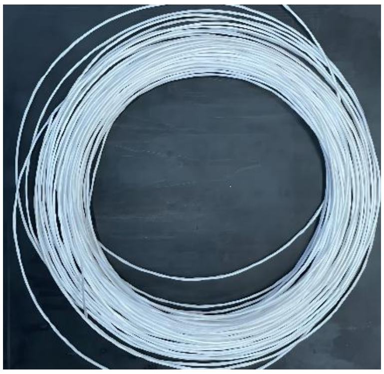

Figure 2b. Filament morphology under 250° C extrusion

Extrusion at 230 °C produced a filament with optimal properties, characterized by a uniform diameter and a translucent white appearance. This temperature effectively minimized thermal degradation while preserving structural integrity, yielding high-quality filament suitable for additive manufacturing. These findings underscore the critical role of precise temperature regulation in optimizing the extrusion process and enhancing filament reliability.

3.1.2 Effect of nozzle diameter, cooling rate on the quality of filament

The nozzle diameter plays a significant role in determining the quality and consistency of extruded filament in polymer processing [De Assis 2024; Kuram 2016]. The filament diameter is shown in Fig. 3. With the use of a 2 mm nozzle, the filament diameter remains consistently within the range of 1.75 ± 0.05 mm (See Fig. 3a), ensuring reliability for subsequent 3D printing processes. In contrast, with the use of a 4 mm nozzle, significant fluctuations in filament diameter are noted, with measurements ranging from approximately 1.60 mm to 1.90 mm (See Fig. 3b). These inconsistencies negatively affect the 3D printing process, potentially leading to nozzle clogging or insufficient material flow, thereby compromising print quality and product integrity.

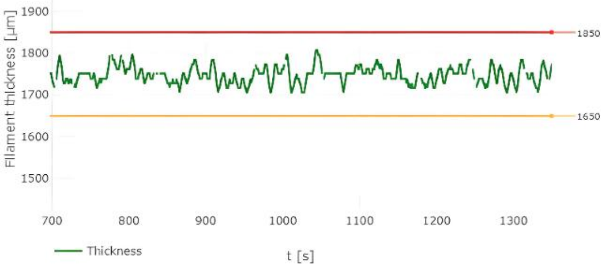

Figure 3a. Filament diameter using 2 mm nozzle

Figure 3b. Filament diameter using 4 mm nozzle

A smaller nozzle diameter, specifically 2 mm, results in a higher shear rate due to the smaller cross-sectional area. This increased shear promotes better homogenization of the polymer blend, ensuring a more uniform flow and reducing phase separation, which is crucial for maintaining consistent filament quality [De Assis 2024].

The cooling efficiency of the filament is another critical factor affected by nozzle size. Filaments produced through a 2 mm nozzle have a greater surface area relative to their volume, leading to faster and more uniform cooling. This reduces the risk of thermal inconsistencies and dimensional instability. In contrast, a 4 mm nozzle extrudes a larger volume of material that cools more slowly and unevenly, which cause shrinkage and variability in filament size.

PC, with a high glass transition temperature (~147 °C) and viscosity, tends to warp under rapid cooling. A slower cooling rate (fan speed 0 - 10 %) preserves molecular integrity, reduces stress, and minimizes defects. In contrast, ABS, with a lower glass transition temperature (~105 °C), undergoes greater shrinkage, requiring a higher cooling rate (fan speed 20 - 30 %) to ensure dimensional accuracy and minimize warping. For the PC/ABS blend, an optimal fan speed of 10 - 20 % balances the faster solidification of ABS with the stability needs of PC, ensuring uniform filament quality [Silva 2022].

Furthermore, the draw-down ratio (DDR), which is the ratio of the nozzle diameter to the filament diameter, also contributes to filament stability. A 2 mm nozzle results in a lower DDR (DDR = 1.14), meaning that the extrusion process is more stable and the target filament diameter is more easily maintained. In comparison, the 4 mm nozzle leads to a higher DDR (DDR = 2.29), which increases instability and results in larger fluctuations in filament size [Kuram 2016].

3.2 Hardness

In this study, the hardness of 3D-printed samples was evaluated to compare the mechanical performance of different filament types. To ensure objective evaluation, each printed sample was measured five times at different points. The specific hardness values are presented in Tab. 4.

Number of measurement	ABS	PC	PC/ ABS	PC-C	ABS-C
1.	51.5	79.0	72.9	76.1	68.7
2.	51.9	78.9	73.7	76.5	70.2
3.	52.0	78.2	72.3	75.9	71.5
4.	52.4	77.5	71.7	77.6	69.5
5.	52.2	78.4	73.2	76.6	69.1
Average value	52.0 ±0.34	78.4 ±0.60	72.8 ±0.78	76.5 ±0.66	69.8 ±1.1

Table 4. The hardness of samples

Fig. 4 illustrates the hardness values of various printed samples, highlighting the distinct differences between ABS and PC materials. The hardness of the PC-C filament and the extruded PC filament showed similar values of 78.4 ± 0.6 and 76.5 ± 0.66, respectively. In contrast, the extruded ABS filament exhibited the lowest hardness value of 52.0 ± 0.34, while the commercial ABS-C filament had a significantly higher hardness of 68.7 ± 1.10, indicating the presence of additives that enhance hardness. The PC/ABS blend filament exhibited an intermediate hardness value of 72.8 ± 0.78, indicating the synergistic effect of PC and ABS.

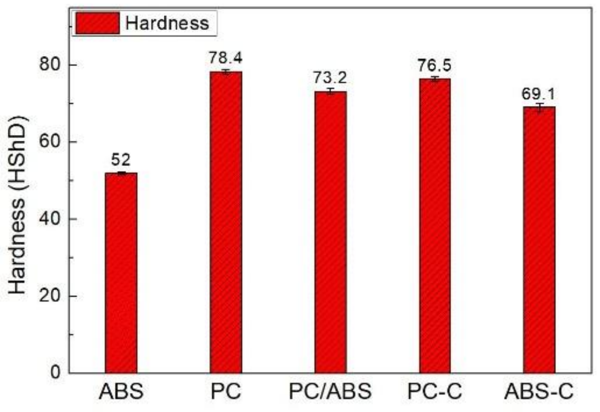

Figure 4. The hardness of samples

3.3 Tensile test

The tensile test results are presented in Fig. 5. The tensile properties of extruded PC and commercial PC were found to be nearly identical. Both exhibited a yield strength (δ_y) of 57 MPa, with an ultimate tensile strength (δ_m) of 56.6 MPa. The strain at maximum stress (ε_m) was 3.0 %, while the elongation at break (ε_b) reached 3.6 %.

In contrast, extruded ABS demonstrated a significantly higher elongation at break (ε_b) of 4.8 %, compared to 2.3 % for commercial ABS. However, the yield strength of extruded ABS was notably lower (17.8 MPa) than that of the commercial counterpart (33.6 MPa). The differences in mechanical properties are attributed to the presence of additives used in industrial ABS production, which enhance mechanical. In contrast, self-fabricated ABS fibers are typically produced without such additives, resulting in reduced mechanical performance. A summary of the corresponding mechanical properties is provided in Tab. 5.

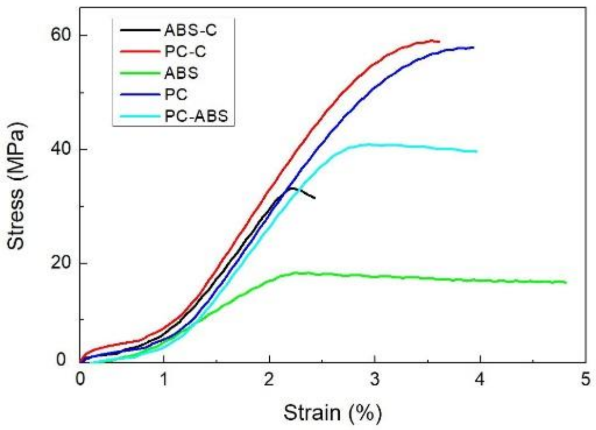

Figure 5. Tensile test stress-strain diagram

Material	δ_y (MPa)	δ_m (MPa)	ε_m (%)	ε_b (%)	δ_b (MPa)
PC	57.1	56.6	3.0	3.6	46.2
PC-C	57.0	56.6	2.9	3.6	50.4
ABS	17.8	17.8	1.8	4.8	15.1
ABS-C	33.6	33.5	1.7	2.3	29.3
PC/ABS	39.2	39.2	2.3	4.0	32.8

Table 5. Tensile test results

The PC/ABS blend exhibited intermediate mechanical properties, combining favorable characteristics of both PC and ABS. The yield strength (δ_y) was 39.2 MPa, which is lower than that of PC but significantly higher than that of ABS. Moreover, the blend achieved an elongation at break (ε_b) of 4.0 %, which surpasses that of PC while being comparable to extruded ABS. These findings indicate that the PC/ABS blend successfully integrates the mechanical advantages of both polymers, offering a balance between strength and ductility.

3.4 Bending test

The flexural properties of the 3D-printed specimens were evaluated using three-point bending tests, and the results are presented in Fig. 6 and Tab. 6. To ensure statistical reliability, each specimen was tested three times, and the average values with standard deviations are reported.

As illustrated in Fig. 6, significant differences in flexural performance were observed among the tested materials. PC-C exhibited the highest flexural strength and modulus, with a maximum stress (δ_{fm}) of 79.4 MPa and a modulus (E_f) of 1813.4 MPa, slightly outperforming the extruded PC, which reached a maximum stress of 80.2 MPa and a modulus of 1612.7 MPa. The slight increase in stiffness and flexural yield strength (δ_{fc} = 59.6 MPa) of PC-C compared to PC (δ_{fc} = 57.6 MPa) indicate that the commercial PC filament contains reinforcement additives that enhance rigidity.

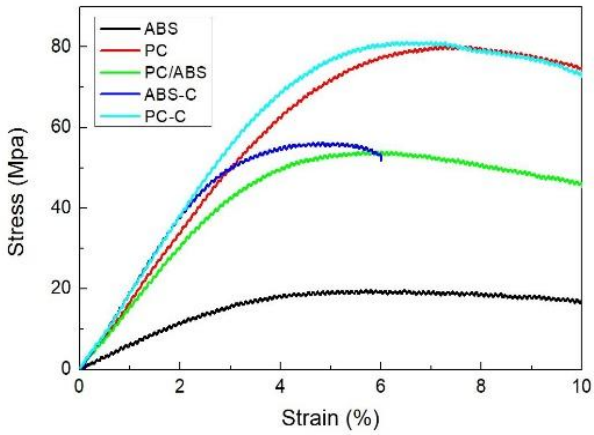

Figure 6. Bending test stress-strain diagram

PC/ABS demonstrated an intermediate behavior, with a flexural modulus of 1480 MPa and a maximum stress of 53.9 Mpa. The improved flexural strength over ABS (δ_{fm} = 20.4 MPa) but lower values compared to PC, highlight the synergistic effect of the PC and ABS combination.

Material	E_f (MPa)	δ_{fc} (MPa)	δ_{fm} (MPa)	ε_{fm} (%)
PC	1612.7	57.6	80.2	7.3
PC-C	1813.4	59.6	79.4	6.5
ABS	684.5	17.1	20.4	5.6
ABS-C	1760	51.1	55.2	5.1
PC/ABS	1480	44.1	53.9	5.8

Table 6. Bending test results

Among the ABS-based specimens, ABS-C exhibited significantly higher flexural performance than extruded ABS, with a flexural modulus of 1760 MPa compared to 684.5 MPa, and a maximum stress of 55.2 MPa, approximately 2.7 times higher than that of ABS (20.4 MPa). This substantial difference indicates that the commercial ABS filament contains modifications or reinforcements that greatly enhance its mechanical strength.

Furthermore, ABS showed the lowest mechanical performance among all tested materials, with a flexural modulus of 684.5

MPa, a flexural yield strength of 17.1 MPa, and a maximum stress of 20.4 MPa, which is consistent with its lower stiffness and weaker interlayer bonding in 3D printing. In terms of ductility, extruded PC exhibited the highest strain at maximum stress (ε_{fm} = 7.3 %), followed by PC/ABS (5.8 %) and ABS (5.6 %), while PC-C (6.5 %) and ABS-C (5.1 %) were relatively lower.
Overall, the results confirm that PC-based filaments provide superior flexural strength, while the commercial ABS-C exhibits significantly enhanced properties compared to standard ABS. The PC/ABS blend offers a balanced mechanical performance, making it a potential alternative when moderate stiffness and strength are required.

4 CONCLUSIONS

This study demonstrates the critical role of extrusion parameters in determining the quality and mechanical performance of PC, ABS, and PC/ABS filaments for 3D printing. An extrusion temperature of 230 °C provided the best balance of material integrity and uniformity. PC required a slow cooling rate (0 – 10 %), while ABS performed optimally with a faster cooling rate (20 – 30 %) to minimize defects. A 2 mm nozzle ensured filament consistency, whereas a 4 mm nozzle led to diameter fluctuations.
Mechanical characterization demonstrated that extruded PC/ABS blends achieve a balance between strength and ductility, with a yield strength of 39.2 MPa and elongation at break of 4.0 %. Extruded PC maintained high hardness (76.5 ± 0.66) and tensile strength (57 MPa), while ABS exhibited greater ductility (4.8 %) but lower strength (17.8 MPa). Flexural testing confirmed that PC/ABS blends outperformed extruded ABS and offered intermediate properties between commercial PC and ABS.
These findings underscore the importance of process optimization in filament extrusion to achieve high-quality, defect-free materials for 3D printing applications. The ability to tailor mechanical properties through precise parameter control is crucial for industries such as aerospace, automotive, and defense, where performance and reliability are paramount.

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