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Comparative Performance of Material Extrusion and Vat Photopolymerization Systems for Automotive Product

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Abstract

Additive Manufacturing (AM) has emerged as a rapidly developing technology with applications ranging from product visualization and prototype fabrication to actual production. Various types of AM are available on the market, broadly categorized into industrial-grade and consumer-grade machines. This study focuses on consumer-grade printers, which are more affordable and widely accessible. Among these, the two most commonly used technologies are Material Extrusion (ME) and Vat Photopolymerization (VP). While the performance of ME printers has been widely investigated, comparative studies between ME and VP remain limited. In this work, three automotive product samples (logo, paddle shift, and shift knob) were printed using both ME and VP consumer-grade machines. Each print was evaluated in terms of dimensional accuracy, printing time, and final product mass, with the slicer predictions compared to actual measurements. The findings indicate that VP printers outperform ME in terms of printing speed and energy efficiency. On the other hand, FDM printers offer advantages in material cost and dimensional accuracy in the Z direction. Furthermore, the study examines the potential of consumer-grade printers to support automotive product prototyping efficiently and practically.

Keywords: *Additive Manufacturing, Material Extrusion, Vat Photopolymerization, dimensional accuracy.*

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INTRODUCTION

The use of additive manufacturing (AM) has grown significantly in recent years, moving well beyond its original role as a tool for rapid prototyping [1], [2]. Initially, 3D printing was primarily employed to create visual models that allowed designers and engineers to better communicate concepts and evaluate product appearance. Over time, its applications expanded to include the production of functional prototypes that could be tested for performance, fit, and durability. Today, additive manufacturing is increasingly applied in the fabrication of end-use products across various sectors, demonstrating its potential not only as a prototyping method but also as a viable production technology for aerospace, automotive, medical, and other sectors [3], [4]. This shift reflects advancements in printing technologies, materials, and machine accessibility, which have collectively made 3D printing an essential part of modern product development and manufacturing processes.

According to ASTM standards, additive manufacturing technologies are classified into seven categories: material extrusion (ME), powder bed fusion, material jetting, binder jetting, vat photopolymerization (VP), direct energy deposition, and sheet lamination [5]. At the entry-level scale, particularly for consumer use, material extrusion, commonly known as fused deposition modeling (FDM), is the most widespread technology due to its simplicity and affordability [6], [7], [8], [9].

Fused Deposition Modeling (FDM), also known as Fused Filament Fabrication (FFF), is an additive manufacturing process that uses material extrusion. In this method, the material (plastic filament) is melted and deposited layer by layer to form the desired object. The materials used in FDM are thermoplastics in filament form [10]. The material for ME technology is thermoplastic filament, and the most common polymers used are ABS and PLA [11], [12].

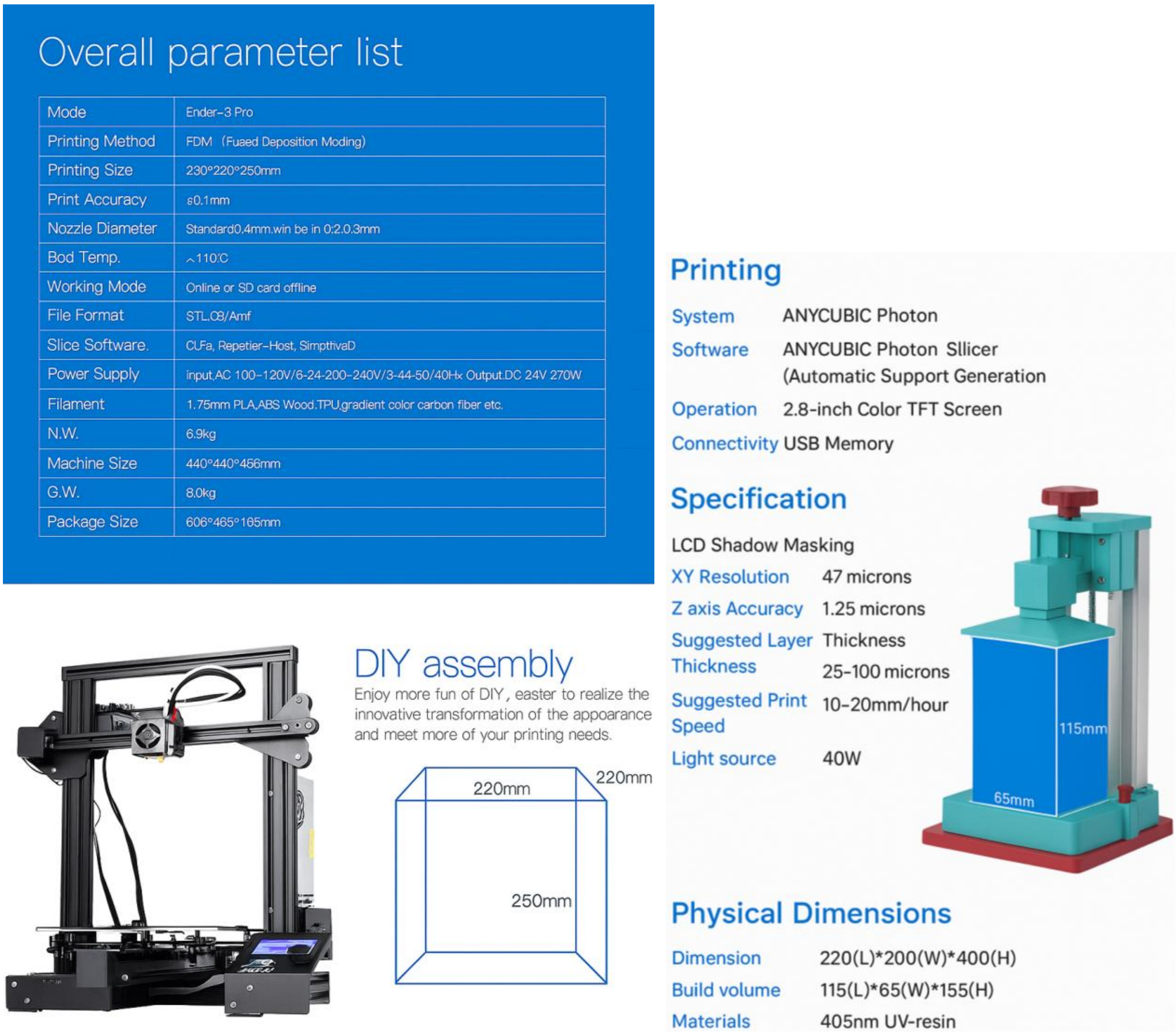
Alongside FDM, low-cost vat VP printers have also become increasingly accessible in recent years. Most VP resins are acrylate-based photocurable polymers, which often form very stiff and brittle networks [13], [14]. VP is a type of 3D printing technology used to create products layer by layer through photochemical processes. The system consists of a movable platform that moves up and down, and beneath it is a resin tank with a screen at the bottom that projects UV light to cure the resin. The light passes through an LCD screen that forms a pattern corresponding to the desired object, so only the illuminated areas solidify [15]. Once one layer has hardened, the platform moves upward to prepare for the next layer. In VP technology, several methods are available, including DLP, SLA, LCD, and CLIP [16]. Among these, low-cost 3D printers most commonly use the LCD-based approach.

The growing popularity of these two technologies can largely be attributed to their relatively low purchase price and operating cost, which make them attractive options for hobbyists, students, and small-scale product developers. Szykiedans and Credo (2016) investigated the mechanical properties of parts produced by low-cost FDM and SLA/VP printers, focusing on tensile strength and elastic modulus of ABS, Z-Glass, and a photopolymer resin. Their findings showed that FDM generally yielded higher tensile strength than VP, with Z-ABS, Z-Glass, and photopolymer resin reaching 1.12 GPa, 1.43 GPa, and 246 MPa, respectively. While this work provided useful baseline data on tensile performance, it did not address other critical aspects such as printing speed, dimensional accuracy, or process–structure relationships. These gaps limit the broader applicability of their results for engineering contexts, highlighting the need for more comprehensive evaluations of low-cost additive manufacturing technologies[17].

With the availability of these two alternatives, entry-level users and hobbyists now face a choice between FDM and VP technologies. A direct comparison of their capabilities is therefore necessary to guide the selection of the most appropriate AM technology for specific needs. Important aspects that can be evaluated include printing speed, final part weight, and dimensional accuracy. By systematically comparing these parameters, this study aims to highlight the advantages and limitations of each technology and to determine their suitability for consumer-level prototyping, particularly in applications where cost efficiency and functional performance are both critical.

METHODS AND ANALYSIS

In this study, two consumer-grade 3D printers were selected to represent the two most common additive manufacturing technologies at the entry level. The Ender 3 Pro was used as the machine for material extrusion (ME/FDM), while the Anycubic Photon was employed for vat photopolymerization (VP) with LCD technology. The technical specifications of both printers are presented in Figure 1. Since the two machines utilize different printing mechanisms and curing methods, a number of parameters were stan-

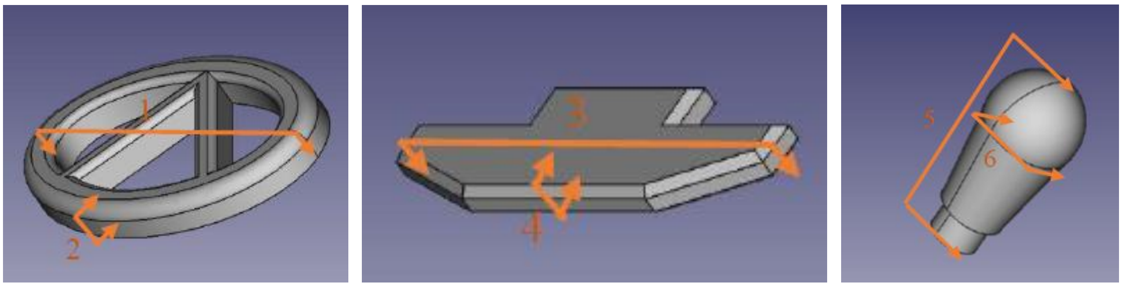


(a) (b)

Figure 1. The specification of a) Ender 3 Pro, b) Anycubic Photon 3D printing machine

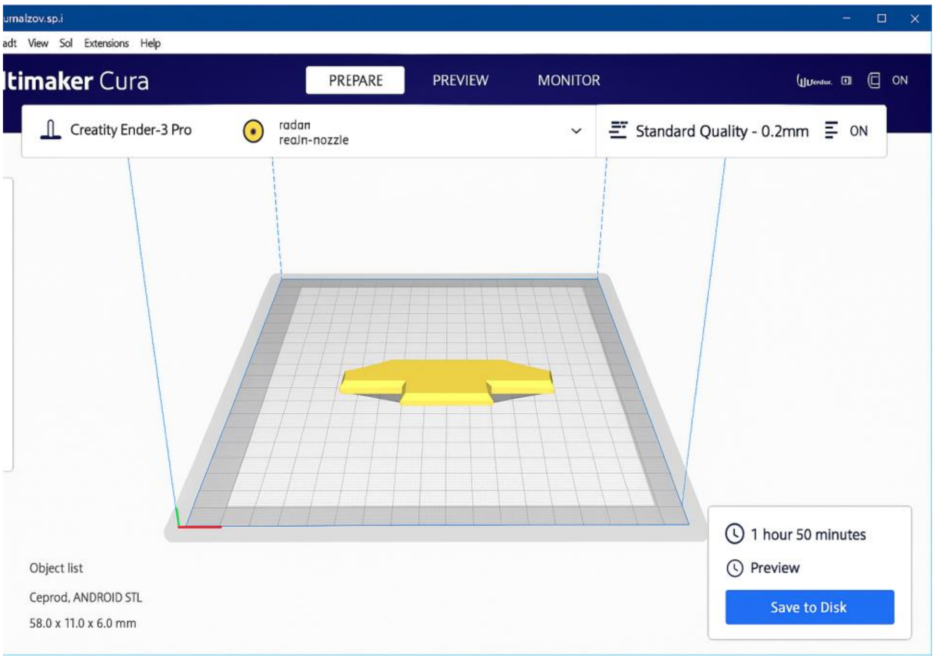
Table 1. Material specification

Material specification	Ender 3 Pro	Anycubic Photon
Printing method	FDM / ME	LCD shadow masking
Material	PLA 1.75 mm	Basic resin (acrylate-based)
Material density	1.23 g/cm^3	1.13 g/cm^3
Melt Flow Index	5（190°C/2.16kg）	N/A
Viscosity	N/A	250-350 mPa·s

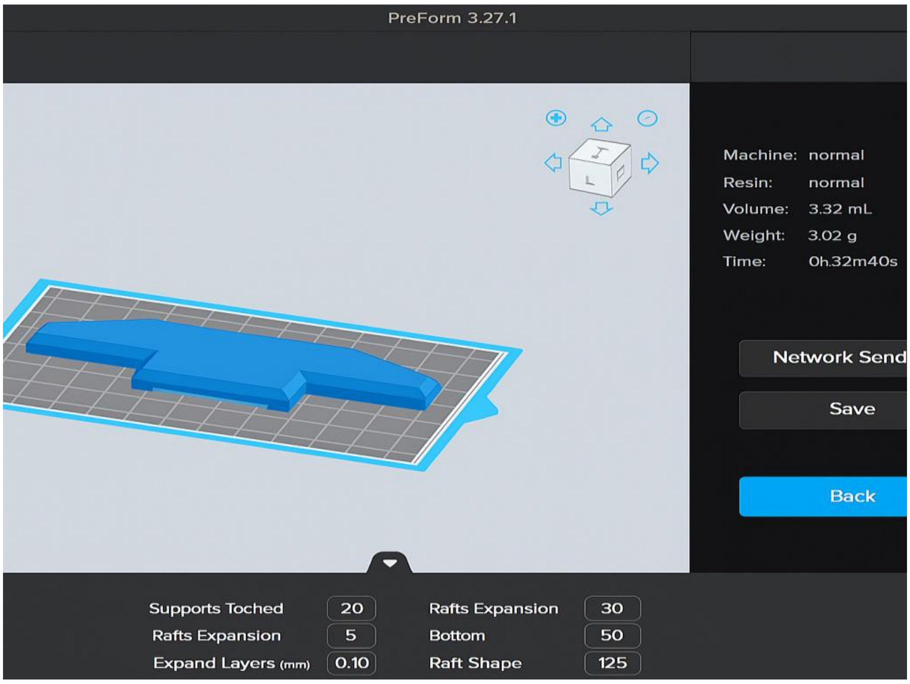


(a) (b) (c)

Figure 2. The printed object and the measurement location of a) Logo, b) Paddle shift, and c) Shift knob



(a)



(b)

Figure 3. The display of paddle shift during the slicing process in a) Cura, and b) Chitubox slicing software

dardized to ensure a fair comparison. These included print orientation, support placement, and layer height, all of which were set to 0.2 mm. Furthermore, all specimens were positioned directly on the build plate in order to maintain equal overall part heights between the two technologies, minimizing discrepancies caused by slicing or print setup. Table 1 lists the material specifications.

To evaluate performance across different geometries, three automotive objects were selected as test models: a logo, a paddle shift, and a shift knob, as illustrated in Figure 2. These objects were chosen because they represent a variety of shapes, ranging from flat and thin features to curved and volumetric forms. Each model was printed twice, and we selected three different models instead of producing multiple samples of a single model. This approach was taken because 3D printing products generally yield comparable results in terms of printing speed, dimensional accuracy, and mass. Figure 2 also presents the location where the measurements were taken. It should be noted that the measurement location is for measuring the thickness (in height or z-axis direction) and for the lateral dimension. All parts were printed as solid models without the use of infill, ensuring that the mechanical comparison would reflect the bulk properties of the materials rather than variations in print density. The logo and paddle shift were fabricated at a 1:1 scale, while the shift knob was reduced to a 1:2 scale to match the build volume constraints of the VP printer.

Figure 3 illustrates the slicing step for the paddle shift sample in Cura and Chitubox slicing software. For slicing and machine preparation, Ultimaker Cura was employed for the ME process, whereas Chitubox was used for the VP process. The material used for ME was 1.75 mm PLA filament (eSun), while the VP specimens were produced using Anycubic's standard photopolymer resin from the starter pack.

All printing was carried out with a flat orientation directly on the build plate to avoid height discrepancies between VP and ME specimens. Each type of specimen was printed twice, with one object produced in each print run, to provide a sufficient dataset for comparison. Following fabrication, all specimens were subjected to dimensional measurement (Mitutoyo digital caliper), weighing (Labtronics GL-103), and print time recording as the initial stages of performance evaluation.

RESULTS AND DISCUSSIONS

Figure 4 shows the 3D printing results of each object. Figure 4(a) presents the results from Ender 3 Pro using ME technology, and Figure 4(b) shows the results from the Anycubic Photon from VP technology. For VP prints, a washing process with Isopropyl Alcohol and an additional curing process were required. Next, the performance of the printed result in terms of dimension accuracy, time, and weight will be discussed.

Dimension accuracy

The results in Table 2 show that both Material ME and VP technologies are able to produce parts with reasonable accuracy, particularly in the X–Y direction. Most of the errors recorded in this plane are below one percent, which means both methods can replicate the length and width dimensions of the reference model with good consistency.

The difference becomes more noticeable when the measurements are taken in the Z-direction, which corresponds to thickness or height (highlighted in gray). In the ME process, the Z-dimension errors generally fall in the range of 0.08% to 6.67%. For example, at the 6 mm reference point in the paddle shift, the ME process produced a value of 5.60 mm, giving an error of 6.67%. In the logo object, where the reference thickness was 10 mm, ME produced results between 3.5% and 4% error. These values indicate that while there is a slight underestimation in thickness, the deviation remains relatively controlled and repeatable.

An important factor contributing to the more consistent Z-dimension accuracy in

(a) (b)

Figure 4. The printing results of each object from a) Ender 3 Pro, b) Anycubic Photon 3D printing machine

Table 2. Dimension measurement comparison of the printed product from ME and VP

Object	Measurement location	Reference	ME		VP	
			Measurement results (mm)	Error (%)	Measurement results (mm)	Error (%)
Logo	1	100.00	99.70	0.30%	100.10	0.10%
	2	10.00	9.65	3.50%	9.15	8.50%
	1	100.00	99.80	0.20%	99.95	0.05%
	2	10.00	9.60	4.00%	9.10	9.00%
Paddle Shift	3	100.00	100.10	0.10%	100.50	0.50%
	4	6.00	5.60	6.67%	4.95	17.50%
	3	100.00	100.10	0.10%	100.10	0.10%
	4	6.00	5.65	5.83%	4.45	25.83%
Shift knob	5	60.00	59.80	0.33%	58.75	2.08%
	6	28.5	29.20	2.46%	28.45	0.18%
	5	60.00	59.95	0.08%	58.90	1.83%
	6	28.5	29.15	2.28%	28.55	0.18%

Table 3. Error measurement comparison of X-Y direction vs Z direction.

	X-Y direction		Z direction	
	ME	VP	ME	VP
Error from reference	0.30%	0.10%	3.50%	8.50%
	0.20%	0.05%	4.00%	9.00%
	0.10%	0.50%	6.67%	17.50%
	0.10%	0.10%	5.83%	25.83%
	2.46%	0.18%	0.33%	2.08%
	2.28%	0.18%	0.08%	1.83%
Average	0.91%	0.19%	3.40%	10.79%
STD	0.011	0.002	0.027	0.093

ME is the behavior of the molten filament during extrusion. When passing through the hot nozzle, the polymer melt experiences both viscosity reduction and the influence of surface tension. The surface tension helps maintain a stable, continuous flow, preventing excessive spreading or collapse as the material is deposited. The filament used in this study has a Melt Flow Index (MFI) of 5 g/10 min (190 °C/2.16 kg), which represents moderate flowability. This balance allows the filament to flow smoothly through the nozzle without being overly fluid, ensuring adequate interlayer bonding and reducing the risk of sagging or dimensional distortion. As a result, ME benefits from predictable layer formation, which partly explains why it produces more reliable Z-direction accuracy than VP.

The VP process, however, shows a much higher level of inaccuracy in the same Z-direction measurements. Errors of 8–9% were observed in the logo object, while in the paddle shift, the error reached as high as 25.83% for the 6 mm feature. This contrasts sharply with VP's performance in the X–Y plane, where the error is generally less than 1%. The large deviations in Z suggest that VP has more difficulty maintaining accuracy in layer height control. Table 3 describes the error of the X-Y direction compared to the Z direction. It is clear from the average value that the X-Y direction shows less error than the Z direction.

One of the reasons behind this problem is that the calibration procedure in VP systems is difficult compared to that in ME systems [18], [19]. Since VP relies on the curing of liquid resin with light, precise control of layer thickness is critical. Any slight error in calibration, exposure time, or resin leveling tends to accumulate with each layer, leading to larger deviations in the vertical direction. ME, on the other hand, builds layers through controlled filament deposition, which appears to give a more stable outcome for height dimensions, even though it may not match VP's precision in surface detail.

From these results, it can be seen that VP is superior in achieving high accuracy on flat surfaces and detailed features in the X–Y plane (Table 3). However, it struggles in maintaining accuracy in the Z-direction, where ME shows more consistent results. For applications that prioritize dimensional accuracy in thickness or height, ME is the more reliable choice in terms of a low-cost system due to calibration issues. On the other hand, for parts that require fine surface finish and precise detailing in the horizontal plane, VP remains a strong candidate, provided that improvements in calibration and process control are made to reduce Z-direction errors

Printing time

The printing time results reveal clear differences between the ME and VP processes (Table 4), both in terms of agreement with slicer predictions and overall speed. For the ME process, the actual printing times are close to the estimates from Cura, although slight variations appear depending on the object. In the logo, the predicted and actual times matched almost exactly (276 minutes predicted, 276 and 274 minutes measured). For the paddle shift, the predicted time was 115 minutes, while the actual printing took around 122 minutes, showing a small increase of about 6–7 minutes. Similarly, for the shift knob, Cura predicted 255 minutes, but the actual runs finished at 247 minutes, slightly shorter than expected. These small differences are likely due to machine-specific factors such as acceleration settings, print pauses, or slicing assumptions that do not fully capture real extrusion dynamics. Overall, Cura provides a reliable estimation of print duration for ME, with differences typically within 5%.

In contrast, the VP process shows a very different trend. The actual printing times recorded are noticeably longer than those predicted by Chitubox. For example, the logo was predicted at 35 minutes but took 36 minutes in practice, which is a very small difference. However, for the shift knob, the discrepancy is much larger: Chitubox predicted 147 minutes, yet the actual print time reached 195 minutes. This pattern suggests that while VP slicer estimates are reasonably close for small objects, they tend to underestimate the required time for larger or taller parts, likely because of additional factors such as resin recoating, lifting movements, and stabilization periods that extend the total process.

Despite these discrepancies, one key observation is that VP is consistently faster than ME. Even with the underestimated slicer predictions, VP finishes printing in a fraction of the time compared to ME. For example, while the shift knob required about 247 minutes in ME, the same object could be produced in VP within 195 minutes. The difference is even more striking in smaller parts: the paddle shift took over 120 minutes in ME but only 28 minutes in VP. This speed advantage is inherent to the VP process, as it cures entire layers simultaneously, rather than depositing material line by line as in ME.

In summary, ME provides printing times that closely match Cura predictions, with only minor variations. VP, on the other hand, shows a tendency for Chitubox to underestimate print durations, especially for larger parts, but still delivers much faster results overall. From a production standpoint, VP offers a significant time advantage, making it more suitable for rapid prototyping where turnaround speed is critical. ME, while slower, may be preferred in cases where more predictable timing and material control are required. However, the postprocessing of the VP approach also takes time for the fully cured final part that needs to be considered [20], [21].

The duration of the printing process has a direct impact on the amount of power consumed, as the longer a machine operates, the more energy it requires. In this case, the Anycubic Photon operates at around 40 watts, while the Ender 3 Pro requires a significantly higher power of about 270 watts to run its heating elements and three servo motors. This difference highlights that the Anycubic Photon is notably more efficient in terms of energy usage, making it the better option when considering power performance

Table 4. Printing time comparison of the printed product form ME and VP

Object	Sample number	ME		VP (gram)	
		Cura (minute)	Actual (minute)	Chitubox (minute)	Actual (minute)
Logo	1	276	276	35	36
	2	276	274	35	36
Paddle Shift	1	115	122	26	28
	2	115	122	26	28
Shift knob	1	255	247	147	195
	2	255	247	147	195

Table 5. Mass comparison of the printed product form ME and VP

Object	Sample number	ME		VP	
		Cura (gram)	Actual (gram)	Chitubox (gram)	Actual (gram)
Logo	1	29.10	29,99	33.00	28.45
	2	29.10	29.93	33.00	28.77
Paddle Shift	1	13.20	13.13	15.00	11.87
	2	13.20	13.16	15.00	12.02
Shift knob	1	25.90	27.76	31.00	28.26
	2	25.90	27.87	31.00	28.22

and overall operating costs.

Printed part mass

The mass measurement of the printed parts highlights some interesting differences between the two printing technologies (Table 5). For the Material ME process, the actual mass values are very close to those predicted by the slicing software (Cura). For example, in the logo samples, the estimated mass was 29.10 grams, and the measured values were 29.99 grams and 29.93 grams, giving only a small difference of less than 1 gram. A similar trend appears in the paddle shift and shift knob, where the actual values are slightly higher than the slicer prediction, but still within a narrow margin. This shows that Cura provides a reliable estimation of part mass for ME, with the actual prints consistently ending up just a little heavier than the software estimate. This slight increase could be due to additional filament usage in the form of extrusion overlap, slight over-extrusion, or differences in print settings such as wall thickness and infill density.

In contrast, the VP process shows a much larger discrepancy between the slicer (Chitubox) prediction and the actual mass of the printed parts. For all three objects, Chitubox predicted noticeably higher masses compared to the measured results. For instance, the logo was predicted at 33 g but actually measured at around 28.5 g, a difference of more than 4 grams. The same pattern is seen in the paddle shift (15 g predicted, but only around 12 g actual) and the shift knob (31 g predicted, but around 28 g actual). Unlike ME, where the prints turned out slightly heavier, VP parts are consistently lighter than predicted. This suggests that Chitubox tends to overestimate resin usage, possibly because it calculates mass based on theoretical solid volume without fully accounting for drainage, resin shrinkage during curing, or light penetration that may reduce effective material density in certain areas.

When comparing the two technologies, the ME process produces parts with more predictable and stable mass values, very close to what the slicing software estimates. VP, on the other hand, shows greater variation, with actual parts weighing significantly less than predicted. From a practical standpoint, this means ME is more consistent when weight accuracy is critical, while VP may require further adjustment or calibration in the slicer settings to match reality better. When comparing the mass of the printed products, both technologies produce nearly the same weight, with only about a 1-gram difference. However, the material cost shows a significant contrast: the standard resin used in the Anycubic printer is roughly twice as expensive as PLA filament. This means that, from the material cost perspective alone, producing a part with VP technology is about twice as costly as using ME technology.

Finally, prototyping plays a crucial role in automotive product development, as it allows manufacturers to evaluate form, fit, and function before moving to mass production. By linking the technical results of accuracy, speed, and mass with prototyping needs, the study directly contributes to decision-making in the early design and development stages of automotive components [22].

CONCLUSIONS

Based on the comparison of dimensional accuracy, mass, and printing time, it is clear that both VP and ME have distinct strengths and weaknesses. ME shows more consistent results in the Z-direction, with smaller errors in thickness or height compared to VP, which struggles to maintain accuracy vertically due to calibration and curing limitations. In terms of mass prediction, ME also demonstrates better agreement between slicer estimation (Cura) and actual measurements, with only slight increases in real values. VP, on the other hand, consistently produces lighter parts than predicted by Chitubox, which points to a need for improved calibration in resin volume estimation and curing control.

When printing time is considered, VP holds a strong advantage, completing parts much faster than ME, regardless of object size. This speed advantage makes VP highly suitable for rapid prototyping, especially where fast turnaround is more critical than absolute mass or dimensional accuracy. ME, while slower, offers better predictability in both part weight and dimensional control, making it more reliable for applications that require functional accuracy and material consistency. Overall, VP can be seen as the more time-efficient option, while ME stands out for its stability and low material cost. In conclusion, prototyping serves as a vital stage in automotive product development, and by connecting the technical findings on accuracy, speed, and mass to prototyping requirements, this study provides valuable insights for decision-making in the early phases of component design and development.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare that they have no potential conflicts of interest regarding the research, authorship, and/or publication of this article.

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REFERENCES

[1] S. Yilmaz, “Comprehensive analysis of 3D printed PA6 .6 and fiber-reinforced variants: Revealing mechanical properties and adhesive wear behavior,” *Polym. Compos.*, vol. 45, no. 2, pp. 1446–1460, Jan. 2024, doi: 10.1002/pc.27865.

[2] M. W. Rosyadi, A. D. Prayoga, A. S. Mukti et al., “Optimization of Fused Deposition Modeling (FDM) Machine Process Parameters for Polylactic Acid (PLA) Surface Roughness Using the Taguchi Approach,” *J. Mech. Eng. Sci. Innov.*, vol. 4, no. 1, pp. 35–44, Jul. 2024, doi: 10.31284/j.jmesi.2024.v4i1.5999.

[3] S. Berretta, K. Evans, and O. Ghita, “Additive manufacture of PEEK cranial implants: Manufacturing considerations versus accuracy and mechanical performance,” *Mater. Des.*, vol. 139, pp. 141–152, Feb. 2018, doi: 10.1016/j.matdes.2017.10.078.

[4] W. S. Tan, Y. Y. Tanoto, N. Jonoadji et al., “The Effect of Cooling and Temperature in 3D Printing Process with Fused Deposition Modelling Technology on the Mechanical Properties with Polylactic Acid Recycled Material,” *Int. Rev. Mech. Eng. IREME*, vol. 15, no. 12, p. 615, Dec. 2021, doi: 10.15866/ireme.v15i12.21573.

[5] M. Pérez, D. Carou, E. M. Rubio et al., “Current advances in additive manufacturing,” *Procedia CIRP*, vol. 88, pp. 439–444, 2020, doi: 10.1016/j.procir.2020.05.076.

[6] Y. Y. Tanoto, J. Anggono, I. H. Siahaan et al., “The effect of orientation difference in fused deposition modeling of ABS polymer on the processing time, dimension accuracy, and strength,” presented at the INTERNATIONAL CONFERENCE ON ENGINEERING, SCIENCE AND NANOTECHNOLOGY 2016 (ICESNANO 2016), Solo, Indonesia, 2017, p. 030051. doi: 10.1063/1.4968304.

[7] K. Wangsawijaya, Y. Y. Tanoto, D. Wahjudi et al., “A preliminary study of remanufacturing on FDM machine,” presented at the APPLIED PHYSICS OF CONDENSED MATTER (APCOM2023), Štrbské Pleso, Slovak Republic, 2024, p. 020008. doi: 10.1063/5.0181553.

[8] H. Adibi and M. R. Hashemi, “Experimental study on tensile strength of copper microparticles filled polymer composites printed by fused deposition modelling process,” *Rapid Prototyp. J.*, vol. 28, no. 1, pp. 21–31, Jan. 2022, doi: 10.1108/RPJ-08-2020-0199.
[9] A. D. Prayoga, A. S. Mukti, R. D. K. Mahameru et al., “Optimization of Fused Deposition Modeling (FDM) Machine Parameters for Carbon Fiber Tensile Strength Using the Taguchi Method,” *J. Mech. Eng. Sci. Innov.*, vol. 4, no. 1, pp. 45–56, Jul. 2024, doi: 10.31284/j.jmesi.2024.v4i1.5987.
[10] A. Konta, M. García-Piña, and D. Serrano, “Personalised 3D Printed Medicines: Which Techniques and Polymers Are More Successful?,” *Bioengineering*, vol. 4, no. 4, p. 79, Sep. 2017, doi: 10.3390/bioengineering4040079.
[11] R. Febrian, Y. Y. Tanoto, V. Filbert et al., “OPTIMASI MULTIRESPON PADA PROSES 3D PRINTING MATERIAL PLA DENGAN METODE TAGUCHI GREY,” *J. Rekayasa Mesin*, vol. 13, no. 2, pp. 577–588, Sep. 2022, doi: 10.21776/jrm.v13i2.1113.
[12] Y. Y. Tanoto, V. Filbert, R. Febrian et al., “Optimasi Multirespon pada Proses 3D Printing Material ABS dengan Metode Taguchi-PCR Topsis,” *TEKNIK*, vol. 43, no. 2, pp. 147–157, Jul. 2022, doi: 10.14710/teknik.v43i2.43301.
[13] D. A. Rau, M. Kim, B. Xu et al., “Vat Photopolymerization Printing of Modular Soft Stretchable Low-Cost Elastomers,” *ACS Appl. Polym. Mater.*, vol. 7, no. 11, pp. 7566–7574, Jun. 2025, doi: 10.1021/acsapm.5c01217.
[14] M. Pagac, K. Hajnys, Q. Ma et al., “A Review of Vat Photopolymerization Technology: Materials, Applications, Challenges, and Future Trends of 3D Printing,” *Polymers*, vol. 13, no. 4, p. 598, Feb. 2021, doi: 10.3390/polym13040598.
[15] F. Zhang, L. Zhu, Z. Li et al., “The recent development of vat photopolymerization: A review,” *Addit. Manuf.*, vol. 48, p. 102423, Dec. 2021, doi: 10.1016/j.addma.2021.102423.
[16] D. Chekkaramkodi, L. Jacob, M. S. C et al., “Review of vat photopolymerization 3D printing of photonic devices,” *Addit. Manuf.*, vol. 86, p. 104189, Apr. 2024, doi: 10.1016/j.addma.2024.104189.
[17] K. Szykiedans and W. Credo, “Mechanical Properties of FDM and SLA Low-cost 3-D Prints,” *Procedia Eng.*, vol. 136, pp. 257–262, 2016, doi: 10.1016/j.proeng.2016.01.207.
[18] E. Mukherjee, L. Malone, E. Tackett et al., “Monitoring the Calibration of In-Office 3D Printers,” *Dent. J.*, vol. 11, no. 1, p. 20, Jan. 2023, doi: 10.3390/dj11010020.
[19] P. Turek, A. Bazan, P. Kubik et al., “Development of a Calibration Procedure of the Additive Masked Stereolithography Method for Improving the Accuracy of Model Manufacturing,” *Appl. Sci.*, vol. 15, no. 13, p. 7412, Jul. 2025, doi: 10.3390/app15137412.
[20] O. Kordyl, Z. Ztyrna, M. Wojtylko et al., “Optimization of LCD-Based 3D Printing for the Development of Clotrimazole-Coated Microneedle Systems,” *Materials*, vol. 18, no. 7, p. 1580, Mar. 2025, doi: 10.3390/ma18071580.
[21] I. K. Cingesar, M.-P. Marković, and D. Vrsaljko, “Effect of post-processing conditions on polyacrylate materials used in stereolithography,” *Addit. Manuf.*, vol. 55, p. 102813, Jul. 2022, doi: 10.1016/j.addma.2022.102813.
[22] C. W. Elverum and T. Welo, “Leveraging prototypes to generate value in the concept-to-production process: a qualitative study of the automotive industry,” *Int. J. Prod. Res.*, vol. 54, no. 10, pp. 3006–3018, May 2016, doi: 10.1080/00207543.2016.1152406.