

# Consumer Grade 3D Printing: Comparative Mechanical Properties of Material Extrusion and Vat Photopolymerization Systems

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## ABSTRAK

*Teknologi additive manufacturing (AM) secara umum dapat dibagi menjadi sistem kelas industri dan mesin kelas konsumen, di mana yang terakhir lebih hemat biaya dan lebih mudah diakses oleh pengguna yang lebih luas. Dalam segmen konsumen, metode yang paling umum digunakan adalah fused deposition modelling (FDM) dan vat photopolymerization berbasis LCD. Meskipun FDM telah banyak diteliti, perbandingan kinerja secara langsung antara material extrusion (ME) dan vat photopolymerization (VP) masih relatif terbatas. Penelitian ini bertujuan untuk mengisi kesenjangan tersebut dengan mengevaluasi perilaku mekanik dari kedua teknologi. Hasil penelitian menunjukkan bahwa pencetakan berbasis LCD memiliki kinerja yang lebih unggul pada beberapa aspek mekanik tertentu (elongasi), sementara kedua material tingkat pemula menunjukkan kekuatan tarik yang sebanding, yaitu sekitar 31.5 MPa. Sebaliknya, kekuatan lentur pada spesimen yang diproduksi dengan metode ME lebih tinggi, yang menunjukkan bahwa setiap proses memiliki keunggulan tersendiri bergantung pada aplikasi yang diinginkan.*

**Kata Kunci:** printer 3D kelas konsumen, FDM, LCD, PLA, sifat mekanik.

## ABSTRACT

Additive manufacturing (AM) technologies can generally be divided into industrial-grade systems and consumer-grade machines, the latter being more cost-effective and accessible to a broader user base. Within the consumer segment, the most prevalent methods are fused deposition modelling (FDM) and LCD-based vat photopolymerization. Although FDM has been extensively studied, direct performance comparisons between material extrusion (ME) and vat photopolymerization (VP) remain relatively scarce. This study addresses this gap by evaluating the mechanical behavior of both technologies. The results show that LCD-based printing demonstrates superior performance in certain mechanical aspects (elongation), while both entry-level materials achieved comparable tensile strengths of approximately 31.5 MPa. In contrast, the flexural strength was higher in the specimens produced by ME, indicating that each process carries distinct advantages depending on the application.

**Keywords:** consumer-grade 3D printing, FDM, LCD, PLA, mechanical properties.

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## INTRODUCTION

Additive manufacturing (AM), also commonly referred to as 3D printing, rapid prototyping, direct digital manufacturing, layered manufacturing, or tool-less model making, is a process that builds three-dimensional objects directly from CAD data using a layer-by-layer approach [1]. Research on AM began in the 1960s, and its techniques were first brought to market in the 1980s by 3D Systems. Since then, AM has continuously advanced and expanded [2]. Its layer-by-layer fabrication principle provides a key advantage: the capability to produce nearly any geometry that

conventional manufacturing cannot achieve. At the same time, it shortens product development cycles, making AM an effective approach for creating complex and unconventional structures that are otherwise difficult to manufacture using traditional methods [3].

As defined by ASTM standards, additive manufacturing technologies are divided into seven main categories: material extrusion (ME), powder bed fusion, material jetting, binder jetting, vat photopolymerization (VP), direct energy deposition, and sheet lamination [4,5]. At the consumer level, ME, widely recognized as fused deposition modelling (FDM), is the most commonly used additive manufacturing technology, largely because of its ease of use and cost-effectiveness [6]–[8]. FDM, developed by Stratasys in the late 1980s, remains the most widely used 3D printing technology today. The process involves extruding thermoplastic filament through a heated nozzle and depositing it layer by layer to build the desired object [9]. In this technology, thermoplastic filament is employed as the primary feedstock, with ABS and PLA being the most commonly utilized polymers [10]. In addition to FDM, affordable VP printers, particularly those using LCD masking technology, have become increasingly available in recent years due to the cost-effectiveness for consumers. In VP printing, polymeric resins (acrylate-based photocurable) are constrained by process requirements. A thin layer of liquid photopolymer is cured by light, after which the platform shifts to allow fresh resin to flow in. To enable this, the resin must have low viscosity for efficient layer replenishment [11],[12]. At the bottom of the tank, UV light is projected through an LCD screen, which creates a patterned exposure matching the object’s geometry, curing only the illuminated regions of the resin [13].

As FDM and LCD shadow masking technology have become widely available, new users and hobbyists frequently encounter the challenge of selecting the most appropriate option for their projects. A direct comparison of the two processes is valuable, with particular attention to mechanical properties, as these strongly determine practical functionality. However, there is a lack of research addressing this topic, particularly for consumer-grade 3D printers. This work undertakes a structured evaluation of both methods, identifying their benefits and limitations while considering their suitability for consumer-oriented prototyping, where affordability must align with adequate performance.

## METHOD

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 for ME, while Any-cubic Photon was employed for VP using LCD technology. The technical specifications of both printers are presented in Table 1. Since the two machines utilize different printing mechanisms and curing methods, several parameters were standardized 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. Technical specifications of both printers

Specifications	Ender 3 Pro	Any-cubic Photon
Printing method	FDM	LCD shadow masking
Printing size [mm]	220 x 220 x 250	115 x 65 x 155
Printing accuracy/resolution	±0.1 mm	XY: 47 microns, Z: 1.25 microns
Light source	NA	UV LED (405 nm)
Power [W]	270 W	40 W
Material	PLA 1.75 mm	Basic resin
Material density [g/cm <sup>3</sup> ]	1.23	1.13
Tensile strength [MPa]	31.2 (Z direction)	40 - 50
Elongation [%]	2.6	12 - 16
Flexural strength [MPa]	59.8	50 - 60

Tensile and flexural tests were chosen to evaluate the mechanical properties of the starter pack of material from the 3D printing supplier. Flexural testing uses ASTM D790 three-point bending,

and tensile testing uses ASTM D638-4 standard type 4, and 5 specimens were prepared for both tests. All specimens were printed in a vertical orientation to ensure that they conformed to the standard dimensions. A JTM UT C-20 KN (JTM Technology Co., LTD, Taichung, Taiwan) was used. For FDM, a filling density of 50%, a cubic filling pattern, a nozzle temperature of 200°C, and a bed temperature of 60°C were used. Meanwhile, for LCD, the exposure time we use is the standard exposure time prepared by the slicing software. All sample preparation followed ASTM standards before testing, such as storage for more than 24 hours at 50% humidity and 25°C.

## RESULTS AND DISCUSSION

The tensile test results presented in Figure 1 show that specimens fabricated using FDM (PLA) and LCD-based resin printing exhibit nearly identical ultimate tensile strength values of ~31.5 MPa. Despite the similar strength values, the elongation at break differed. FDM-PLA showed only 1.66%, while LCD resin specimens reached 2.85%. This indicates that the resin-based prints demonstrated slightly higher ductility, although both materials fell significantly below their supplier-reported bulk properties. PLA is generally reported with tensile strengths in the range of 50–70 MPa and elongations of 3–6% [14],[15]. However, based on supplier information, the tensile strength of PLA in the z-direction is 31.2 MPa [16], which is similar to the result. Any-cubic Standard Resin is specified at 40–50 MPa with elongations up to 12–16% [17]. The reduced mechanical performance in the printed state reflects the influence of layer adhesion, curing uniformity, and processing anisotropy, which dominate over the intrinsic material capabilities.

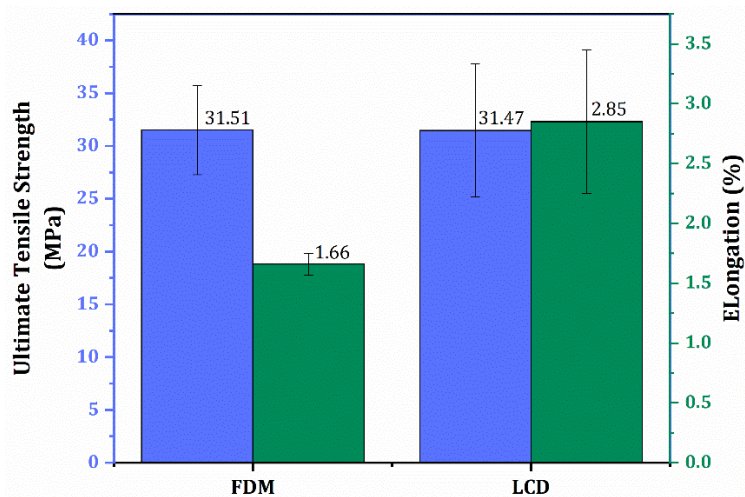


Figure 1. The UTS result and elongation comparison from FDM and LCD technology

All tensile test specimens were printed in a vertical orientation (Z-direction), meaning the tensile load was applied perpendicular to the deposited filament layers. In this configuration, failure is primarily influenced by the interlayer adhesion strength rather than the intrinsic tensile strength of bulk PLA. This explains why the measured UTS (~31.5 MPa) is significantly lower than the supplier-reported value (50–70 MPa). These results reflect the typical anisotropic behaviour of FDM components, where interlayer bonding is the dominant limiting factor in mechanical performance.

The flexural strength results, shown in Figure 2, further highlight this discrepancy between printed and bulk properties. FDM specimens exhibited a flexural strength of 29.56 MPa, outperforming the LCD resin specimens, which only reached 23.56 MPa. According to the supplier, PLA is expected to achieve a flexural strength of approximately 59.8 MPa, while the resin is rated at 40–50 MPa. Once again, both printed materials demonstrate substantially lower strength values compared to their datasheet specifications. This reduction is attributed to the introduction of microstructural defects during layer-by-layer fabrication, insufficient interlayer bonding in FDM, and incomplete polymer crosslinking in photopolymerized resin. Another factor that needs to be considered in FDM is infill density. Figure 2 reveals that FDM shows higher flexural strength but

similar UTS. PLA (FDM) generally has a higher modulus and stiffness compared to standard photopolymer resin. Flexural loading is highly sensitive to elastic modulus.

Although both technologies exhibit similar UTS values (~31.5 MPa), the FDM specimen exhibited higher flexural strength (29.56 MPa) compared to the LCD specimen (23.56 MPa). This difference can be attributed to several factors. First, PLA generally has a higher stiffness than standard photopolymer resins, which positively contributes to flexural resistance. Second, tensile loading exerts uniform stress across the cross-section, making the interlayer interface the dominant failure path in vertically printed FDM parts. In contrast, flexural loading produces a stress gradient, with maximum tensile stress localized at the outer surface and compressive stress on the opposite side. The interlayer interface typically exhibits greater resilience under tension than tension, which partially mitigates anisotropic weakness during bending. Furthermore, LCD-printed photopolymer resins tend to exhibit more brittle behaviour due to their highly cross-linked network structure. Upon bending, crack initiation at the tensile interface can propagate rapidly through the material, resulting in lower flexural strength compared to PLA-based FDM parts.

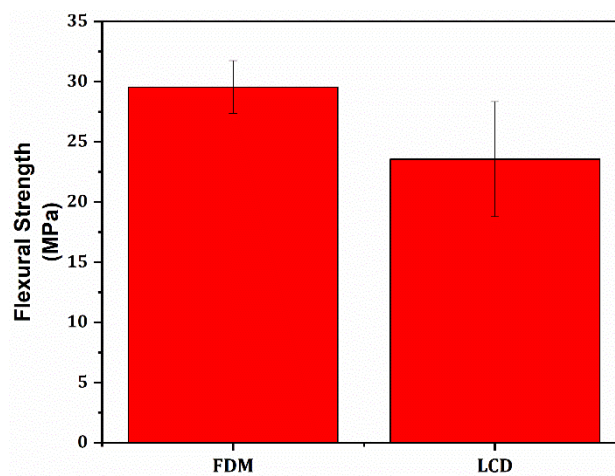


Figure 2. The flexural strength comparison of FDM and LCD technology

Although the experimental results revealed no substantial differences in the mechanical properties of specimens produced by the Ender 3 Pro (FDM) and Any-cubic Photon (LCD), other considerations must be considered when comparing the two technologies. One of the most critical differences lies in the choice of material. FDM relies on thermoplastic filaments such as PLA, which are generally inexpensive and widely available, whereas LCD printing requires photo-curable resins, which are considerably more costly [18]. In terms of printing time, LCD printing offers a clear advantage, as the entire cross-sectional layer is cured simultaneously by light projection, resulting in faster build rates. In contrast, FDM constructs each layer sequentially by extruding material through a moving nozzle, which inherently extends the processing time.

Another important factor is printing accuracy. LCD technology provides superior resolution in the XY plane due to the pixel size of the LCD screen, enabling higher detail fidelity compared to the nozzle-driven deposition in FDM [19]. However, in the z-direction, or layer thickness, both technologies may achieve comparable results when identical layer heights are employed. Cost efficiency must also be considered. While resin itself is more expensive than PLA filament, LCD printers generally consume less power (approximately 40 W) and achieve faster print speeds. This results in lower energy usage and reduced operating costs per part. Consequently, when evaluating the overall performance of the two systems, LCD printing demonstrates advantages in accuracy, speed, and energy efficiency, while FDM maintains benefits in terms of material affordability and accessibility.

## CONCLUSION

The comparison between FDM (Ender 3 Pro) and LCD (Any-cubic Photon) printing demonstrated that, in terms of mechanical performance, both technologies produced specimens with similar tensile and flexural strength, albeit significantly lower than the bulk material specifications

provided by suppliers. This indicates that in consumer-grade 3D printing, mechanical performance is primarily limited by processing factors, such as interlayer adhesion, curing uniformity, and microstructural defects, rather than by the inherent material properties.

Beyond mechanical properties, several practical considerations differentiate the two approaches. FDM benefits from the affordability and accessibility of PLA filament, making it attractive for low-cost prototyping. In contrast, LCD printing employs photo-curable resin, which is more expensive but enables faster build times, higher accuracy in the XY plane, and lower power consumption, thus reducing operating costs. Taken together, these results suggest that for consumer-grade 3D printing, FDM remains a cost-effective option for general use, while LCD printing offers advantages in precision, speed, and efficiency for applications requiring higher dimensional accuracy and surface quality.

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