EXPERIMENTAL COMPARISON OF SILICONE CASTING MOULDS PRODUCED BY ADDITIVE MANUFACTURING TECHNOLOGIES

Stjepan Vranjković* – Bruno Krajačić – Luka Didak – Damir Godec

University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, Zagreb, Croatia

ARTICLE INFO

***Article history*:**
Received: 2. 3. 2026.
Received in revised form: 13. 3. 2026.
Accepted: 15. 7. 2026.

Keywords:
Additive manufacturing
Mould
RTV (Room Temperature Vulcanizing) silicone
FFF (Fused Filament Fabrication)
LCD (Liquid Crystal Display)
PolyJet

DOI: 10.30765/er.3399

Abstract:

Moulds for Room Temperature Vulcanizing silicone casting produced using additive manufacturing technologies are gaining importance in modern production for their rapid, precise, and customizable fabrication. However, various three-dimensional printing methods yield different qualitative traits affecting mould functionality, durability, and applicability. This study compares moulds produced by fused filament fabrication, liquid crystal display vat photopolymerization, and PolyJet material jetting from identical computer-aided design models, assessing surface roughness, dimensional accuracy, hardness, and abrasion resistance via profilometry, three-dimensional optical scanning, and standardized tests. The fused filament fabrication process shows high roughness with visible layer lines, limiting high-precision uses. The liquid crystal display process achieves the lowest roughness and best surface quality, while material jetting offers superior accuracy, hardness, and wear resistance. The results provide a standardized framework for technology selection in the medical industry, specifically for applications requiring high hygienic and anatomical fidelity.

ACCEPTED

1 Introduction

The emergence of additive manufacturing has initiated a profound paradigm shift within the global manufacturing sector, transitioning from traditional subtractive methods toward highly flexible, digital-to-physical production workflows. In the specific field of mould production for Room Temperature Vulcanizing (RTV) silicone casting, this technology is revolutionizing the speed at which complex, functional tools can be realized. Unlike conventional metal tooling, which necessitates extensive lead times and significant capital investment for CNC machining or EDM processes, additive manufacturing enables the rapid, precise, and customizable fabrication of moulds. This is particularly advantageous during the iterative stages of product development and for the manufacturing of patient-specific medical devices where the high cost of traditional moulds cannot be justified by low-volume production. By leveraging technologies such as Fused Filament Fabrication (FFF), Liquid Crystal Display (LCD) photopolymerization, and PolyJet, engineers can now produce intricate geometries that were previously impossible or economically unfeasible to manufacture. These advancements are governed by evolving international standards, such as ISO/ASTM 52900, which provide a unified framework for the classification and validation of these diverse additive processes. A significant challenge in the fabrication of elastomeric medical devices, such as vaginal pessaries, is the stringent requirement for direct and prolonged contact with sensitive human mucosa. In such clinical applications, the morphological fidelity of the mould surface is not merely a technical preference but a critical functional requirement. Excessive surface roughness in the mould directly translates to irregularities on the silicone part, which can complicate both the demoulding process and subsequent sanitization protocols. From

* Corresponding author
E-mail address: stjepan.vranjkovic@permedis.com

a biological perspective, a rough surface finish may facilitate biofilm adhesion or cause mechanical irritation to delicate tissues, potentially leading to complications in long-term use. Therefore, achieving a superior surface finish and ensuring dimensional accuracy are imperative for providing the necessary mechanical support and ensuring patient safety. This necessitates a deep understanding of how each additive technology handles the staircase effect, layer adhesion, and thermal contraction during the solidification process.

The mechanical integrity of the mould material itself is another cornerstone of successful silicone casting. Material hardness and resistance to abrasive wear are essential for preserving the integrity of the cavity over multiple production cycles. During the pouring and curing of RTV silicones, moulds are subjected to internal pressures and localized stresses. Insufficient material hardness can lead to subtle deformations that compromise the geometric tolerances of the final part. Furthermore, the repeated mechanical action of part removal and mould cleaning can lead to progressive abrasion, which gradually degrades the surface quality and compromises the precision required for medical-grade products. Despite the critical nature of these parameters, there remains a notable lack of systematic scientific comparison and comprehensive characterization of moulds produced by different additive technologies.

Current academic literature provides extensive data on the mechanical properties of additive-manufactured parts, yet it fails to offer comprehensive insights into the specific behaviour of these materials when utilized as casting tools. There is an evident gap in the understanding of how photopolymer stability, thermal properties of thermoplastics, and varying printing parameters influence the ability to maintain tight tolerances over time. RTV silicones require moulds that are not only mechanically stable but also chemically compatible to ensure that the cross-linking reaction is not inhibited by the mould material. The aim of this paper is to bridge this critical research gap by experimentally evaluating and comparing the impact of FFF, LCD, and PolyJet technologies on mould functionality. Through a rigorous characterization involving profilometry, 3D optical scanning for dimensional accuracy, Shore D hardness testing, and standardized abrasive wear assessments, this work provides an original contribution to the field. By establishing a standardized framework for technology selection, this study assists the medical and manufacturing industries in meeting the most stringent anatomical and hygienic demands of modern healthcare.

ACCEPTED

2 Materials and methods

Additive manufacturing (AM) builds complex 3D geometries layer-by-layer from digital CAD models, offering superior design freedom, material efficiency, and rapid iteration over traditional subtractive processes like CNC milling or turning. This study evaluates FFF, LCD, and PolyJet technologies for producing RTV silicone casting moulds, assessing key properties via standardized protocols to ensure suitability for precision replication, multi-use durability, and chemical compatibility during room-temperature vulcanization.

2.1 Additive Technologies

Fused Filament Fabrication (FFF, ISO/ASTM 52900 Material Extrusion) selectively melts thermoplastic filaments such as PLA, ABS, PETG, PA, TPU, PEEK, or PEI through a heated nozzle (typically 200–260 °C), depositing material onto a heated build plate where it cools and solidifies layer-by-layer (100–300 μm thickness). This desktop-accessible method excels in low-cost prototyping of simple moulds but suffers from visible layer lines, stair-stepping, warping due to thermal gradients, and moderate surface roughness (Ra ~5–15 μm), necessitating post-processing like sanding for finer finishes [1], [2].

Liquid Crystal Display (LCD, Vat Photopolymerization) employs a monochrome LCD screen (4K/6K/8K resolution) as a mask to selectively expose UV-sensitive photopolymer resins to a LED backlight array, curing entire layers simultaneously (25–100 μm thickness) in a resin vat. This yields exceptionally smooth surfaces (Ra <2 μm) and high detail resolution for intricate features, using rigid, flexible, transparent, or biocompatible resins; limitations include smaller build volumes (e.g., 130×80×160 mm), screen degradation over time, brittle prints requiring post-UV curing (5–10 min), and moisture sensitivity during storage/handling [3].

PolyJet (Material Jetting) inkjet-prints micro-droplets (16–18 μm diameter) of acrylic photopolymers jetted from multiple printheads, instantly cured by UV lamps during continuous platform movement, enabling multi-material/durometer parts (e.g., rigid VeroWhite, flexible Agilus30 TangoBlack) with glossy finishes (Ra ~1–3 μm) and ultra-fine layers (14–20 μm). It allows simple removing complex supports by water jet or ultrasonics/NaOH baths, though at premium material/equipment costs and potential long-term UV-induced

embrittlement [2], [4]. Table 1 shows process parameters for FFF, LCD, and PolyJet technologies used in mould fabrication.

Table 1. Process parameters for FFF, LCD, and PolyJet technologies used in mould fabrication.

Technology	Layer thickness, mm	Print orientation	Infill, %	Support	Printing speed (mm/s)
FFF	0.2	Horizontal (Flat)	15	None	300
LCD	0.05	Horizontal (Flat)	N/A (Solid)	None	1.5*
PolyJet	0.016	Horizontal (Flat)	N/A (Solid)	FullCure 705	1000**

** For LCD technology, speed refers to the vertical lifting speed of the build platform.*
*** For PolyJet technology, speed refers to the maximum linear scanning speed of the print head.*

ACCEPTED

2.2 Surface Roughness Assessment

Surface roughness is determined through tactile profilometry in accordance with ISO 3274:1996, ISO 4287, and ISO 21920-3 standards. Gaussian filtering isolates roughness from waviness and form errors by passing short wavelengths (λs, λf, λc), with cut-off values (e.g., λc = 0.08–8.0 mm; ln = 5×lr) defined by ISO 21920-3:2021 for Ra 0.02–10 μm, Rz 0.1–50 μm, and RSm 0.013–4 mm ranges. A stylus traces microtopography on flat mould surfaces, analysed per ISO 4287 to yield Ra (arithmetic mean deviation) and Rz (mean peak-to-valley height). Results are influenced by manufacturing technology, material, orientation, and post-processing [5], [6].

2.3 Dimensional Accuracy Measurement

Dimensional accuracy of moulds is evaluated using optical 3D scanning based on structured light triangulation: a projector casts phase-shifted fringes onto the surface, captured by stereo cameras to generate point clouds (5 million points per scan). Comparison with CAD models yields quantitative deviations and colour-coded maps. Shiny, transparent, or mirror-like surfaces are matted with TiO_2/ethanol spray. Multiple scans (4–6 positions per mould) are aligned via fiducial markers or best-fit algorithms in software such as ZEISS Inspect, eliminating the need for position tracking. Blue light is preferred due to minimal natural interference [7].

2.4 Hardness Testing

Hardness is a mechanical property characterizing material resistance to indentation by a harder body, serving as an indicator of mechanical durability under friction, load, or abrasion. For polymers, including those from additive manufacturing, Shore scales are predominantly used, with Shore D applied to rigid polymers. This method involves pressing a conical indenter into the specimen under standardized load and dwell time using a durometer, yielding readings on a 0–100 scale (higher values indicate greater resistance to local deformation). The procedure follows ISO 868:2003, specifying specimen thickness, contact duration, and ambient conditions. Results are influenced by material properties, homogeneity, layer orientation in additive processes, and surface finish [8], [9].

2.5 Abrasion Resistance Evaluation

Abrasive wear is the progressive loss of material from a surface due to mechanical interaction with a rough or hard contact surface. For moulds and tools, wear resistance is critical for longevity, functionality, and dimensional stability during repeated use. The ASTM G65 rubber-wheel dry-sand test standardizes evaluation by pressing specimens against a rotating chlorobutyl rubber wheel (60 Shore A) while feeding quartz sand (212–300 μm) between them, simulating low-stress scratching abrasion. Mass loss after defined cycles quantifies wear rates as absolute loss or relative index. Factors influencing results include material hardness,

surface roughness, additive manufacturing layer orientation, abrasive type/size, contact pressure, and test duration [10].

2.6 RTV Silicone Casting and Mould Requirements

Silicones are elastomeric materials based on siloxane (Si–O–Si) structures, offering high thermal stability, chemical inertness, elasticity, and ageing resistance. They are categorized as RTV (Room Temperature Vulcanizing), HTV (High Temperature Vulcanizing), and LSR (Liquid Silicone Rubber), with RTV being two- or one-component systems curing via addition or condensation at ambient conditions. RTV excels in simple applications, rapid processing without heat, and precise detail replication, finding applications in medical devices, electronics, dental technology, and prototyping.

RTV silicone casting involves pouring liquid into moulds for room-temperature curing, ideal for sensitive geometries. Mould quality critically determines casting outcomes: low surface roughness ensures detail transfer, dimensional accuracy preserves geometry, mechanical robustness enables repeated use, and chemical stability prevents cure inhibition. This study assesses additive-manufactured moulds (FFF, LCD, PolyJet) against RTV demands as a reference benchmark, without direct casting [11], [12].

3 Results

This chapter presents the mould fabrication and results from the experimental part of the study. It analyses a mould intended for producing a silicone pessary. The pessary is a medical aid designed to provide mechanical support to pelvic organs in individuals facing pelvic prolapse and urinary incontinence, and it is used as the most common method of conservative treatment for pelvic organ prolapse (POP) [11]. The model fabrication is described, and test specimens were produced using three different 3D printing technologies: FFF, LCD, and PolyJet. Subsequently, the results of measurements and tests are presented: surface roughness, dimensional accuracy, hardness, and abrasive wear. For the evaluation of surface roughness, abrasive wear, and hardness, three test specimens were fabricated for each manufacturing technology and testing method. The reported values represent the arithmetic means of measurements.

3.1 Mould Model Fabrication

The mould used in this study was designed in Onshape CAD software (Onshape (PTC), USA) based on a 3D model of a silicone vaginal pessary, with dimensions and geometry defined by functional requirements of the final product and exported as STL for AM (FFF, LCD, PolyJet) (Figure 1). The four-component mould (70 × 60 × 50 mm closed: bottom plate, slider 1, slider 2, top plate) facilitates clean demoulding while preserving geometry, assembled in a specific sequence via interlocking features for precise alignment (Figure 2).

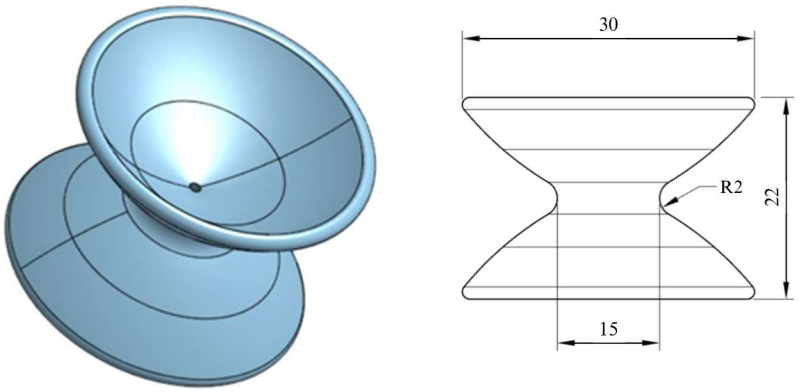


Figure 1. 3D model of the vaginal pessary (left) and vaginal pessary model with marked basic dimensions (right) [11].

ACCEPTED

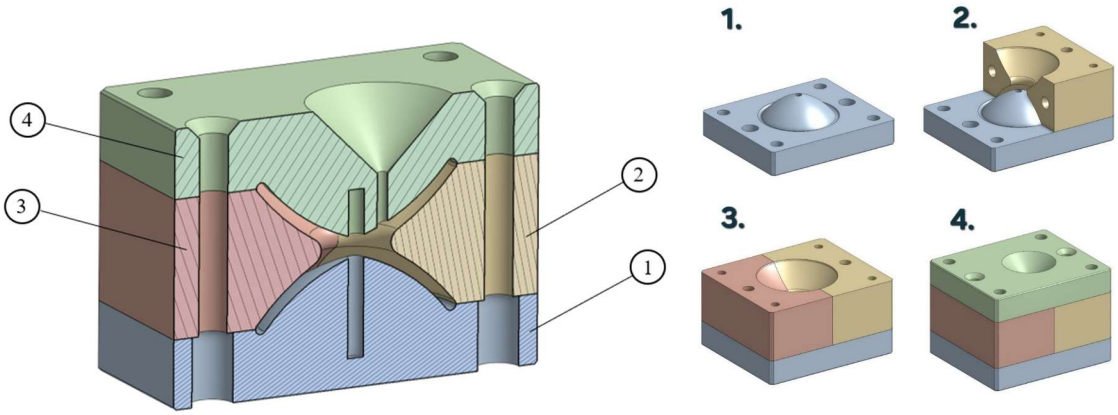


Figure 2. Longitudinal cross-section of the mould with marked components: 1 – bottom plate, 2 – slider 1, 3 – slider 2, 4 – top plate (left) and assembly procedure of mould components for silicone vaginal pessary casting in steps (right).

ACCEPTED

FFF moulds printed on Creality Ender-3 V2 (Creality, China) using PLA filament required support removal and light sanding of mating surfaces, though characteristic layer lines persisted on horizontal faces. LCD moulds from Anycubic Halot-Mage (Anycubic, China) with standard photopolymer resin detached cleanly post-exposure, underwent distilled water rinse, isopropanol ultrasonic cleaning, and 5-minute UV post-curing, yielding glossy surfaces ready for immediate assembly (Figure 3). PolyJet moulds produced on Stratasys J850 Digital Anatomy (Stratasys, USA) printer employed VeroWhitePlus rigid photopolymer with gel supports, necessitating high-pressure WaterJet cleaning (3 bar) followed by 5-minute ultrasonic bath in 2% NaOH solution, resulting in smooth, precise multi-part assemblies (bottom plate, slides 1/2, top plate) suitable for casting without additional refinement (Figure 3).

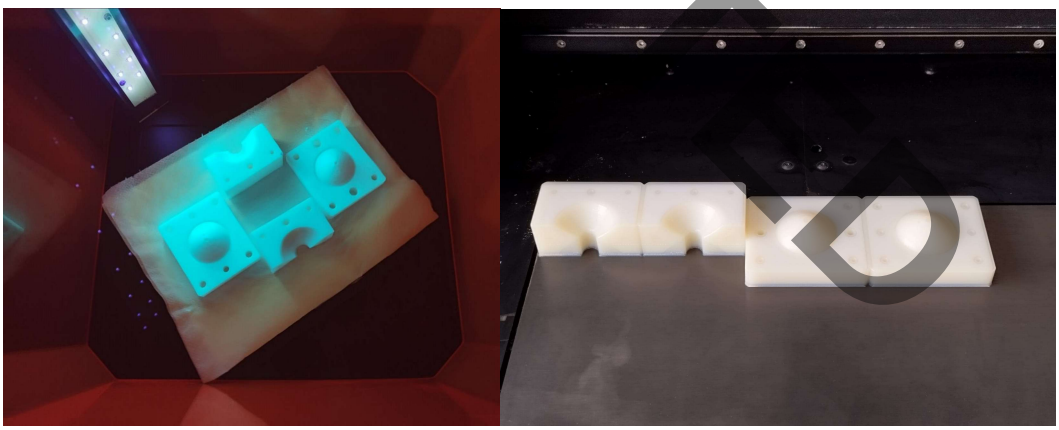


Figure 3. Post-curing in a chamber of mould parts made using LCD technology (left) and mould parts on the PolyJet printer's build platform (right).

3.2 Surface Roughness

Surface roughness measurements were conducted using the Perthometer S8P (Perthen/Mahr, Germany) stylus profilometer, converting vertical displacements from diamond tip contact into electrical signals for 2D profile analysis per ISO 21920-3:2021. Gaussian filtering separated roughness from waviness, with cut-off λc = 2.5 mm for FFF and PolyJet specimens and λc = 0.8 mm for LCD (2 µm tip radius); six replicate profiles were acquired per specimen. Average Ra and Rz values were: FFF (Ra ≈ 12 µm, Rz ≈ 60 µm), LCD (Ra ≈ 0.14 µm, Rz ≈ 0.75 µm), and PolyJet (Ra ≈ 6 µm, Rz ≈ 36 µm), reflecting characteristic surface quality differences, roughest for FFF, smoothest for LCD, intermediate for PolyJet (Figure 4). LCD and PolyJet

yielded superior results due to the use of liquid photopolymers and advanced jetting/masking techniques, which allow for significantly finer layer deposition compared to the extrusion of semi-molten thermoplastic filaments in FFF.

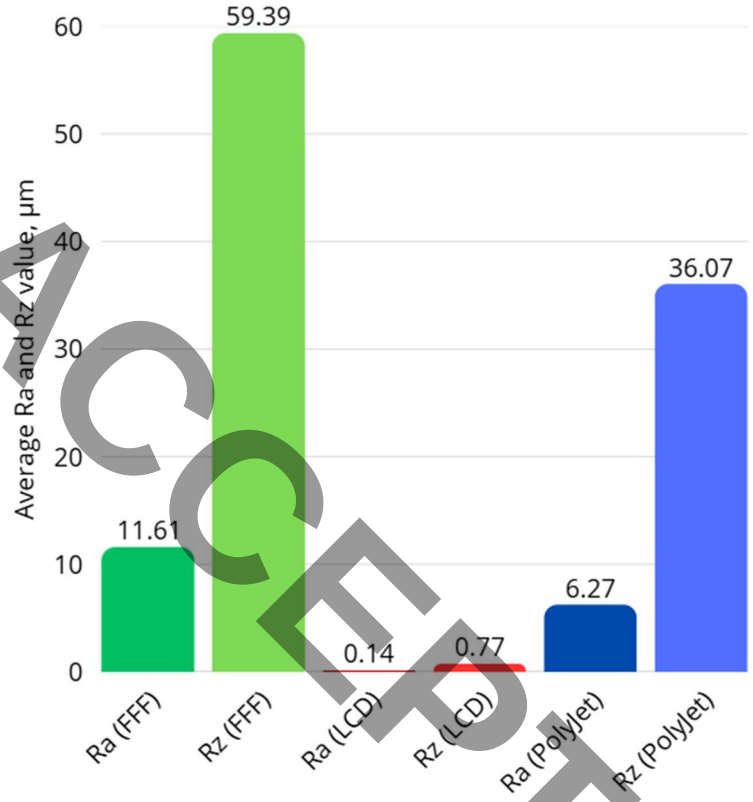


Figure 4. Graphical representation of average surface roughness values (Ra and Rz) for test specimens produced using FFF, LCD, and PolyJet technologies.

3.3 Dimensional Accuracy

Dimensional accuracy of additively manufactured moulds (FFF, LCD, PolyJet) was assessed using the ATOS 5X (ZEISS GOM, Germany) blue-light structured light 3D scanner on a rotary table with fiducial markers for spatial orientation. Surfaces were cleaned but required no matting due to favourable optical properties. Multi-angle scans generated STL meshes, aligned to reference CAD models in ZEISS Inspect (ZEISS, Germany) via pre-alignment, best fit, and RPS alignment, yielding colour-coded deviation maps and numeric control point deviations (Figure 5). The experimental results, summarized in Table 2, indicate that all three technologies exhibited dimensional deviations within a comparable range, primarily between −0.82 mm and +0.62 mm. FFF moulds exhibited significant deviations, reaching a maximum of −0.70 mm on Slider 1, particularly at transitions and edges due to layer thickness limitations and thermal shrinkage. LCD specimens showed localized precision challenges, with the largest negative deviation of −0.82 mm recorded on Slider 2, likely resulting from uneven resin shrinkage during the curing process. Notably, PolyJet technology exhibited unusually poor dimensional accuracy in this study, with deviations ranging from −0.47 mm to +0.59 mm. This performance is contrary to the high precision typically expected from Material Jetting processes. The observed deviations may be linked to residual support material (FullCure 705) or interfacial surface artefacts, which can affect optical scan data and reduce dimensional fidelity. The largest inaccuracies occurred at transitions between mould elements and along geometry edges. Table 2 shows values of minimum and maximum dimensional deviations of mould elements produced using FFF, LCD, and PolyJet technologies.

ACCEPTED

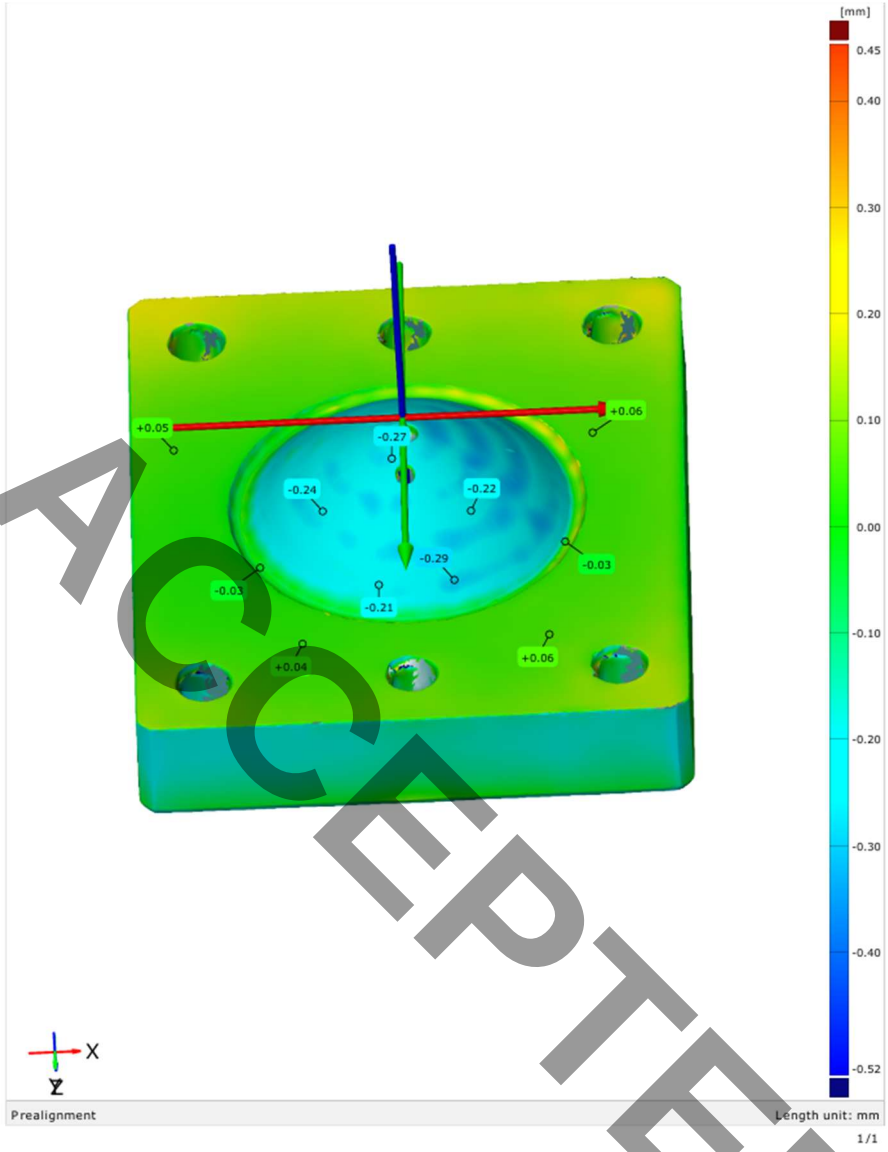


Figure 5. Colour deviation map of dimensional deviations of the upper mould plate made using LCD technology compared to the reference CAD model.

Table 2. Values of minimum and maximum dimensional deviations of mould elements produced using FFF, LCD, and PolyJet technologies.

Mould elements	FFF Min. dev., mm	FFF Max. dev., mm	LCD Min. dev., mm	LCD Max. dev., mm	PolyJet Min. dev., mm	PolyJet Max. dev., mm
Bottom plate	−0.48	0.40	−0.42	0.44	−0.44	0.59
Slider 1	−0.70	0.60	−0.49	0.40	−0.43	0.53
Slider 2	−0.46	0.30	−0.82	0.62	−0.47	0.54
Top plate	−0.49	0.39	−0.52	0.45	−0.43	0.54

3.4 Hardness Testing

Shore D hardness measurements (ISO 868:2003) involved five indentations per specimen (≥6 mm spacing, 5 s dwell time) using a spring-loaded durometer with a 0.090" conical penetrator under a 44.5 N load. FFF specimens averaged 62.4 ± 2.7 (n = 5), reflecting PLA's semi-crystalline structure and interlayer bonding

ACCEPTED

weaknesses from cooling contraction, LCD resins scored 78.0 ± 1.0, balancing rigidity with slight post-cure brittleness, and PolyJet achieved the highest hardness of 85.4 ± 0.5 (Figure 6), due to acrylic photopolymer's dense cross-linking and uniform layer fusion, demonstrating superior resistance to localized plastic deformation critical for repeated mould handling.

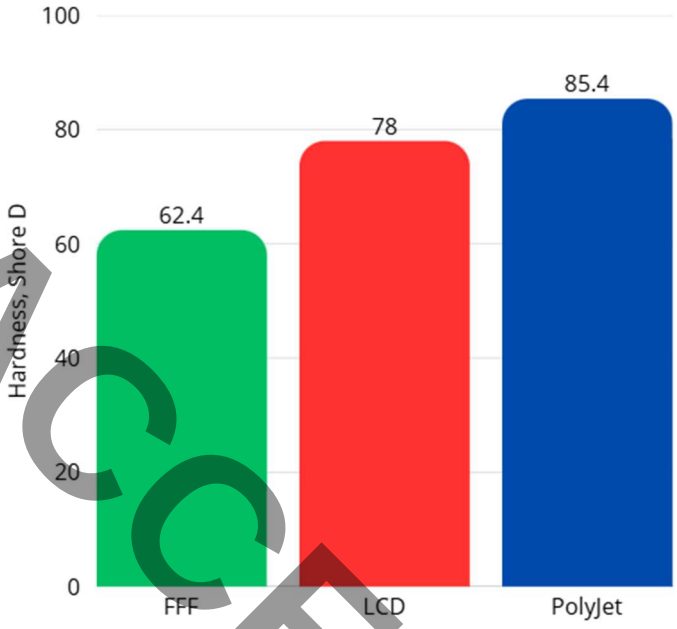


Figure 6. Hardness values for specimens produced using FFF, LCD, and PolyJet technologies.

ACCEPTED

3.5 Abrasion Resistance

Abrasive wear resistance was evaluated per ASTM G65 using 12.7 × 25 × 76 mm specimens, with three samples tested for each technology, for a total of nine tests. The specimens were loaded at 45 N against a 228.6 mm chlorobutyl rubber wheel with 60 Shore A hardness. Ottawa AFS 50/70 silica sand, with a particle size of 212 to 300 µm and a feed rate of 250 to 400 g/min, was continuously introduced between the contact surfaces. Initial masses were measured on an OHAUS Analytical Plus balance with ±0.0001 g precision, and testing proceeded in six incremental stages up to 1600 revolutions total, with cleaning and reweighing after each stage to determine mass loss. Table 3 and Figure 7 show the average mass values and material loss percentage during abrasive wear testing.

Table 3. Display of average mass values of test specimens and material loss percentage during abrasive wear testing.

Number of revolutions	FFF Avg. mass, g	FFF Loss, %	LCD Avg. mass, g	LCD Loss, %	PolyJet Avg. mass, g	PolyJet Loss, %
0	8.9397	0.000	29.5313	0.000	28.7355	0.000
100	8.9288	0.122	29.4787	0.178	28.6657	0.243
200	8.9218	0.201	29.4423	0.301	28.6238	0.389
400	8.9162	0.263	29.3678	0.554	28.5440	0.666
800	8.8823	0.642	29.1956	1.137	28.4572	0.969
1600	8.8076	1.478	28.8882	2.178	28.2569	1.666

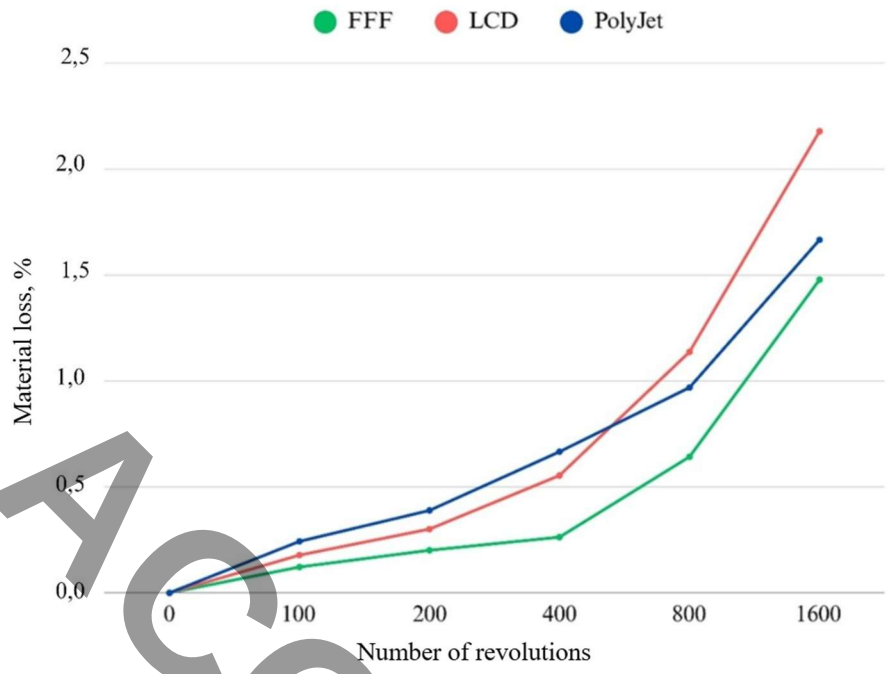


Figure 7. Graphical representation of material loss versus number of revolutions.

ACCEPTED

4 Discussion

The experimental comparison of moulds manufactured using Fused Filament Fabrication (FFF), Liquid Crystal Display (LCD), and PolyJet technologies demonstrates distinct differences in functional and mechanical properties, directly impacting their suitability for RTV silicone casting. Key parameters analysed included surface roughness, dimensional accuracy, hardness, and abrasive wear resistance, with the aim of determining the optimal performance for precise, repeatable, and durable moulds. Surface roughness is a critical parameter for RTV silicone casting as it directly affects the transfer of surface features to the casting, facilitates or complicates demoulding, and influences the subsequent processing and aesthetic quality of the final product.

In this context, FFF technology exhibited the most significant limitations, with Ra values exceeding 12 µm and Rz reaching 60 µm. These high values are a direct result of the 0.2 mm layer thickness and limited resolution, which create a layered structure with visible ridges due to insufficient control over deposition and cooling. Such microstructural irregularities increase friction between the mould and the silicone casting, making part release more difficult and increasing the likelihood of micro-cracks on the finished product. Conversely, LCD technology achieved the best results with exceptionally low Ra (0.14 µm) and Rz (0.77 µm) values. This precision is attributed to the selective UV exposure through an LCD screen, enabling high resolution and a uniform surface almost entirely free of visible layering. Such surface quality promotes the creation of precise RTV moulds with minimal material adhesion. However, despite this exceptional surface quality, LCD specimens exhibited lower mechanical properties in subsequent analyses, which represents a limiting factor for long-term industrial application. PolyJet technology, while not achieving the lowest roughness, demonstrated high uniformity and functional smoothness with Ra values around 6 µm and Rz around 36 µm. This consistent surface quality was achieved through very thin layers (16 µm) and immediate UV polymerization of each droplet.

Hardness analysis further confirmed the mechanical disparities between the studied technologies. FFF specimens exhibited the lowest hardness, indicating lower resistance to deformation and damage under thermal and mechanical loads during repeated casting cycles. This is partly attributed to the 15% internal lattice infill used in FFF specimens. LCD specimens achieved moderate hardness through post-curing in a UV chamber but showed limited abrasion resistance. PolyJet specimens exhibited the highest hardness and resistance, which is crucial for mould longevity and maintaining dimensional stability. This superior resistance to localized plastic deformation was achieved through UV cross-linking during the printing process. Abrasive wear

resistance, evaluated per ASTM G65, showed a clear advantage for FFF specimens, where mass loss was significantly lower than in LCD and PolyJet specimens. Although precise and smooth, LCD specimens demonstrated lower wear resistance, potentially limiting their application in high-cycle industrial processes.

Dimensional accuracy, analysed via ATOS 5X optical scanning and ZEISS Inspect software, highlighted the advantages of advanced technologies, specifically in areas of mould elements that come into contact with the silicone material. While FFF mould elements showed deviations up to ±0.45 mm, which is unacceptable for precision applications, LCD moulds featured more accurate contours within ±0.12 mm. PolyJet specimens were the most precise with deviations under ±0.05 mm, confirming their superiority where high geometric accuracy is paramount. However, when comparing absolute maximum and minimum deviations, it is observed that LCD technology exhibited the largest deviations in specific elements, followed by PolyJet and FFF. For LCD technology, this is attributed to minor deformations occurring during the UV post-curing process. In the case of PolyJet, higher deviations were noted in bore areas where the removal of support material is more difficult. This is further evidenced by the colourimetric maps where maximum inaccuracies occurred in regions where the support material was not entirely removed. Ultimately, all analysed parameters are interrelated and collectively determine mould functionality. High-quality surfaces ensure precise impressions and easy demoulding, while mechanical resistance ensures durability and stability over multiple production cycles. Therefore, technology selection must be based on the interrelationship of these criteria rather than a single isolated parameter.

5 Conclusion

The experimental comparison conducted in this study provides a comprehensive evaluation of Fused Filament Fabrication (FFF), Liquid Crystal Display (LCD), and PolyJet technologies, revealing pronounced disparities in their functional and mechanical performance within the context of RTV silicone mould fabrication. The empirical data concerning surface topography, dimensional fidelity, and mechanical durability demonstrate that the selection of an additive manufacturing process must be strategically aligned with the specific requirements of the final elastomeric product. Surface roughness emerged as a primary differentiator, where LCD technology achieved a state of superior refinement with an Ra value of 0.14 µm. This near-stepless surface quality is a direct result of the high-resolution UV curing process, which minimizes the staircase effect inherent in layer-based manufacturing. Such a high level of smoothness is indispensable for medical applications, such as vaginal pessaries, where surface irregularities can facilitate bacterial adhesion or cause mechanical irritation to sensitive mucosal tissues. The ability of LCD to reproduce micro-features with such fidelity ensures that the subsequent silicone castings maintain the necessary hygienic and aesthetic standards required for clinical certification.

While LCD technology provided the best surface finish, PolyJet technology demonstrated the most balanced overall performance for industrial and clinical applications requiring high hardness and repeatability. PolyJet specimens exhibited the highest Shore D hardness values, reaching approximately 85.4, which translates to superior resistance against localized plastic deformation during the high-pressure phases of silicone pouring and curing. This mechanical stability is crucial for the longevity of the mould, as it prevents the propagation of dimensional errors over multiple production cycles. Although PolyJet's dimensional precision in this particular study was marginally influenced by the presence of residual support material in complex bore areas, its ability to maintain consistent geometries remains superior to that of FFF. This highlights a critical procedural requirement for post-processing in PolyJet technology, where the complete removal of support structures is essential for achieving the maximum potential of the printer's resolution. FFF technology, characterized by Ra values exceeding 12 µm and significant dimensional deviations up to ±0.45 mm, remains constrained by its inherent layer thickness and nozzle resolution. Consequently, FFF is best suited for rapid, low-cost architectural prototyping where the aesthetic and functional demands of the surface are secondary to the overall volumetric representation.

Furthermore, the assessment of abrasive wear resistance revealed that despite its lower infill density, FFF technology showed unexpected resilience, which may be attributed to the specific thermoplastic properties of the PLA used. However, the trade-off remains its inability to capture the intricate details necessary for precision medical devices. In contrast, both LCD and PolyJet allow for the realization of complex internal geometries and sliders required for multi-component moulds. The findings of this research establish a standardized framework for technology selection, confirming that for high-precision, biocompatible silicone

ACCEPTED

products, photopolymerization techniques like LCD and PolyJet are the only viable alternatives. This study contributes an original characterization to the field of rapid tooling, providing the objective data necessary for informed technical decision-making and reducing the reliance on trial-and-error methodologies in the early stages of product development.

The integration of these findings into a decision-making matrix allows engineers to weigh the benefits of surface perfection against mechanical robustness. For instance, while LCD is superior for single-use or high-detail prototypes, PolyJet offers a more durable solution for small-batch production where mould wear becomes a factor. This research effectively demonstrates that the choice of additive technology dictates the entire lifecycle of the mould, from the initial digital design to the final demoulding of the silicone part. Future research should focus on the long-term chemical and thermal stability of these moulds over hundreds of casting cycles to further quantify the economic and functional lifespan of additive-manufactured tools in practical industrial environments. Such investigations would provide deeper insights into the ageing processes of photopolymers and thermoplastics under the repeated chemical stress of silicone vulcanization, further solidifying the role of additive manufacturing in specialized industrial sectors.

References

[1] Sinterit, "Surface finishing of moulds for silicone casting – a case study of FDM, SLA and SLS." Sinterit. [Online]. Available: https://sinterit.com/surface-finishing-of-moulds-for-silicone-casting-a-case-study-of-fdm-sla-and-sls/. [Accessed: 13-Apr-2026].

[2] D. Godec and M. Šercer, Additive Manufacturing. Zagreb, Croatia: Fakultet strojarstva i brodogradnje, 2015.

[3] FacFox Docs, "Vat Polymerization: What Are SLA, DLP, and LCD?." [Online]. Available: https://facfox.com/docs/3d-printing/vat-polymerization/. [Accessed: 25-Jul-2025].

[4] ResearchGate, "PolyJet technology applications for rapid tooling." [Online]. Available: https://www.researchgate.net/publication/318112255_Polyjet_technology_applications_for_rapid_tooling. [Accessed: 25-Jul-2025].

[5] B. Runje, Lectures from the course Theory and Techniques of Measurement. Zagreb, Croatia: Fakultet strojarstva i brodogradnje, 2023.

[6] Geometrical Product Specifications (GPS) — Surface texture: Profile method; Measurement standards – Part 1: Material measures, ISO 5436-1:2000, 2000.

[7] L. Lukačić, "3D mjerenje pomoću optičkog skenera ATOS," Final thesis, Sveučilište Sjever, Koprivnica, Croatia, 2018. [Online]. Available: https://zir.nsk.hr/islandora/object/unin%3A1920/datastream/PDF/view. [Accessed: 25-Jul-2025].

[8] Ž. Alar, "Numerička simulacija ponašanja elastomernih brtvi u dinamičkim uvjetima," Doctoral dissertation, Fakultet strojarstva i brodogradnje, Zagreb, Croatia, 2008. [Online]. Available: https://www.fsb.unizg.hr/atlantis/upload/newsboard/02_06_2008__9070_DOKTORAT_Alar.pdf. [Accessed: 25-Jul-2025].

[9] ISO, "ISO 25178: Geometrical Product Specifications (GPS) – Surface texture: Areal – Part 2: Terms, definitions and surface texture parameters." [Online]. Available: https://www.iso.org/standard/34804.html. [Accessed: 25-Jul-2025].

[10] K. Grilec, S. Jakovljević, and M. Marić, Tribologija u strojarstvu. Zagreb, Croatia: Fakultet strojarstva i brodogradnje, 2019.

[11] S. Vranjković, "Silikonski pesar," Final thesis, Fakultet strojarstva i brodogradnje, Zagreb, Croatia, 2021. [Online]. Available: https://repozitorij.fsb.unizg.hr/islandora/object/fsb%3A11861/datastream/PDF/view. [Accessed: 25-Jul-2025].

[12] Wacker, "Elastosil products – Wacker Chemie AG." [Online]. Available: https://www.wacker.com/cms/en-us/products/brands/elastosil/elastosil.html. [Accessed: 25-Jul-2025].

ACCEPTED