



Printing vs. Milled Zirconia Flexural Strength: A Literature Review

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Abstract

This literature review aims to compare the processes, clinical outcomes, and physical characteristics of 3D printed versus milled monolithic zirconia. 3D printing allows for the creation of intricate geometries with minimal material waste and high customization, making it ideal for tailor-made restorations. In contrast, milling is a well-established and widely used technique known for its accuracy and consistent flexural strength. Both methods have advantages and disadvantages, making them viable choices in modern dentistry.

Objectives

The objective of this abstract is to review the literature on the flexural strength and density of 3D printed versus milled monolithic zirconia. This comparison aims to guide dental professionals in choosing the most suitable method for fabricating high-strength zirconia restorations, considering factors such as material composition and processing that affect overall flexural strength.

Methods

A comprehensive literature search was conducted using the EBSCO database with the keywords “additive and subtractive manufactured zirconia” and “3D-printed and milled zirconia” for in-vitro studies published between 2020 and 2024. Nine articles were identified.

Results

During sintering, dwell times for 3D printed zirconia ranged from 2 to 4 hours, with temperatures between 1450 and 1550°C. In contrast, milled zirconia follows a consistent dwell time of 2 hours at 1450°C. Milled zirconia exhibits higher density, typically ranging from 6.00 to 6.10 g/cm³, while the density of 3D-printed zirconia varies between 5.58 and 6.00 g/cm³. Research articles collectively indicate that milled zirconia demonstrates significantly higher and more consistent flexural strength, typically ranging from 900 to 1200 MPa, compared to 3D-printed zirconia, which ranges from 500 to 820 MPa. This difference in flexural strength is attributed to the uniform microstructure and streamlined protocol of milled zirconia (figure 1) as compared to the more porous and experimental protocol of 3D-printed zirconia (figure 2).

Figures 1 and 2 Courtesy of Mirelle Ruggiero DDS, MSc and Yu Zhang PhD, submitted for publication to Dental Materials June 2024

Table 1. Overview of 3D-printed vs. milled zirconia restorations flexural strength

Milled Density	3D-Printed Density	Milling Dwell Time/ Temperature	3D Printing Dwell Time/ Temperature	Milled Flexural strength	3D-Printed Flexural strength	3D Printing method	Author
Disc 6.10 (g/cm ³)	Disc 5.58-5.90 (g/cm ³)	2 hours at 1450°C	2 hours at 1450°C	900-1200 MPa	620-680 MPa	Binder Jetting	Bergler et al. 2024
Disc 6.07-6.09 (g/cm ³)	Disc 5.90-5.95 (g/cm ³)	2 hours at 1450°C	1.5 hours at 1500°C	900-1200 MPa	650-750 MPa	SLA	Giugliano et al. 2023
Bar 6.05-6.10 (g/cm ³)	Bar 5.95-6.0 (g/cm ³)	2 hours at 1450°C	2 hours at 1500°C	920-1150 MPa	700-800 MPa	L-PBF	Hajjai et al. 2024
Bar 6.05-6.10 (g/cm ³)	Bar 5.85-5.90 (g/cm ³)	2 hours at 1450°C	4 hours at 1550°C	950-1100 MPa	560-610 MPa	SLA	Marsico et al. 2020
Disc 6.05-6.10 (g/cm ³)	Disc 5.90-6.00 (g/cm ³)	2 hours at 1450°C	2.5 hours at 1530°C	1000-1150 MPa	630-680 MPa	DLP	Nakkai et al. 2020
Bar 6.00-6.05 (g/cm ³)	Bar 5.90-5.95 (g/cm ³)	2 hours at 1450°C	3 hours at 1500°C	980-1130 MPa	590-640 MPa	SLA	Revilla-Léon et al. 2022
Disc 6.00-6.06 (g/cm ³)	Disc 5.88-5.94 (g/cm ³)	2 hours at 1450°C	2 hours at 1475°C	970-1120 MPa	590-690 MPa	Binder Jetting	Unnadkat et al. 2023
Cuboid 6.05-6.10 (g/cm ³)	Cuboid 5.96-6.02 (g/cm ³)	2 hours at 1450°C	2 hours at 1500°C	930-1150 MPa	710-820 MPa	SLA	Zenthöfer et al. 2024

Figure 1: Milled sample showing defect introduced by milling tool

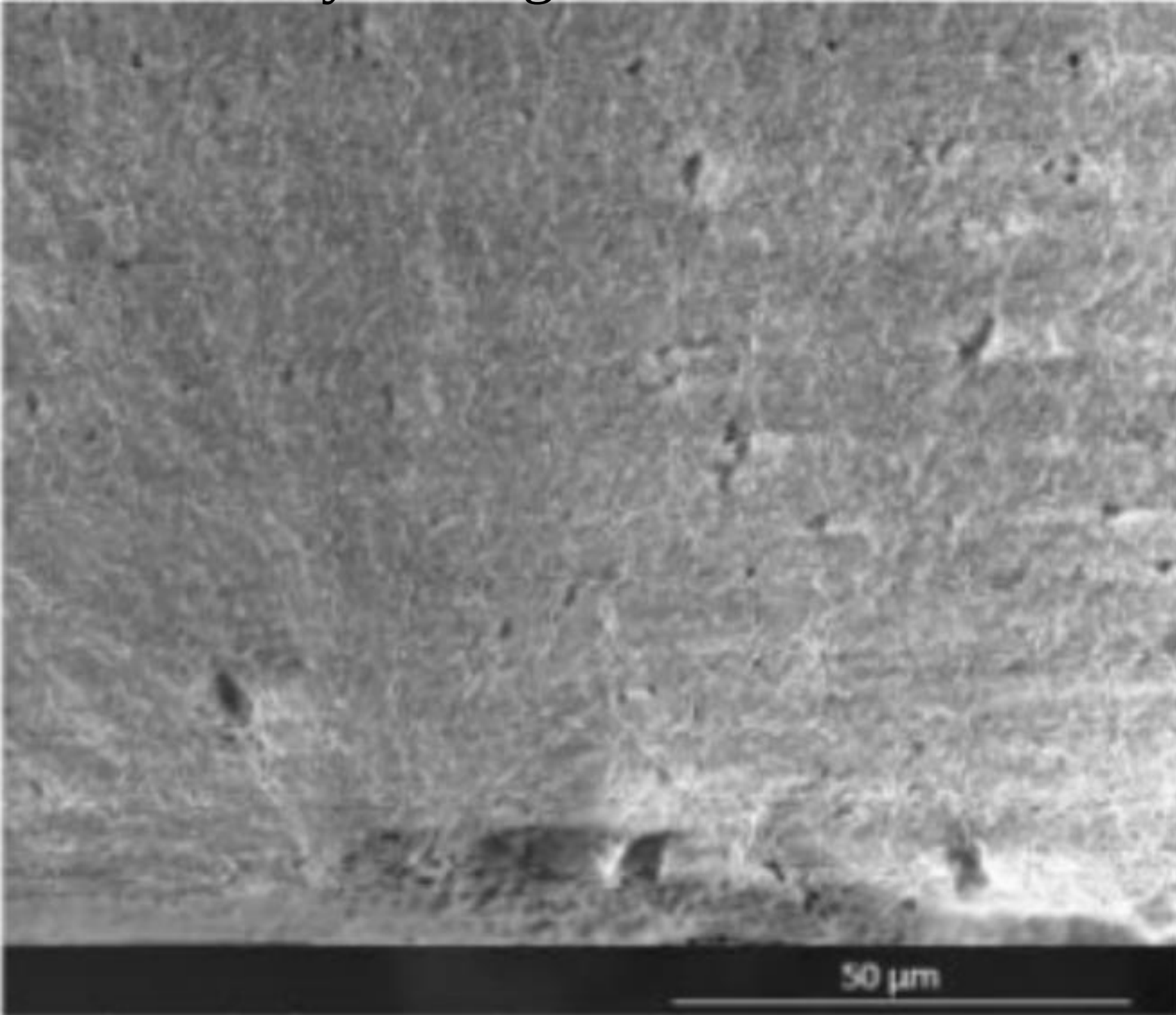
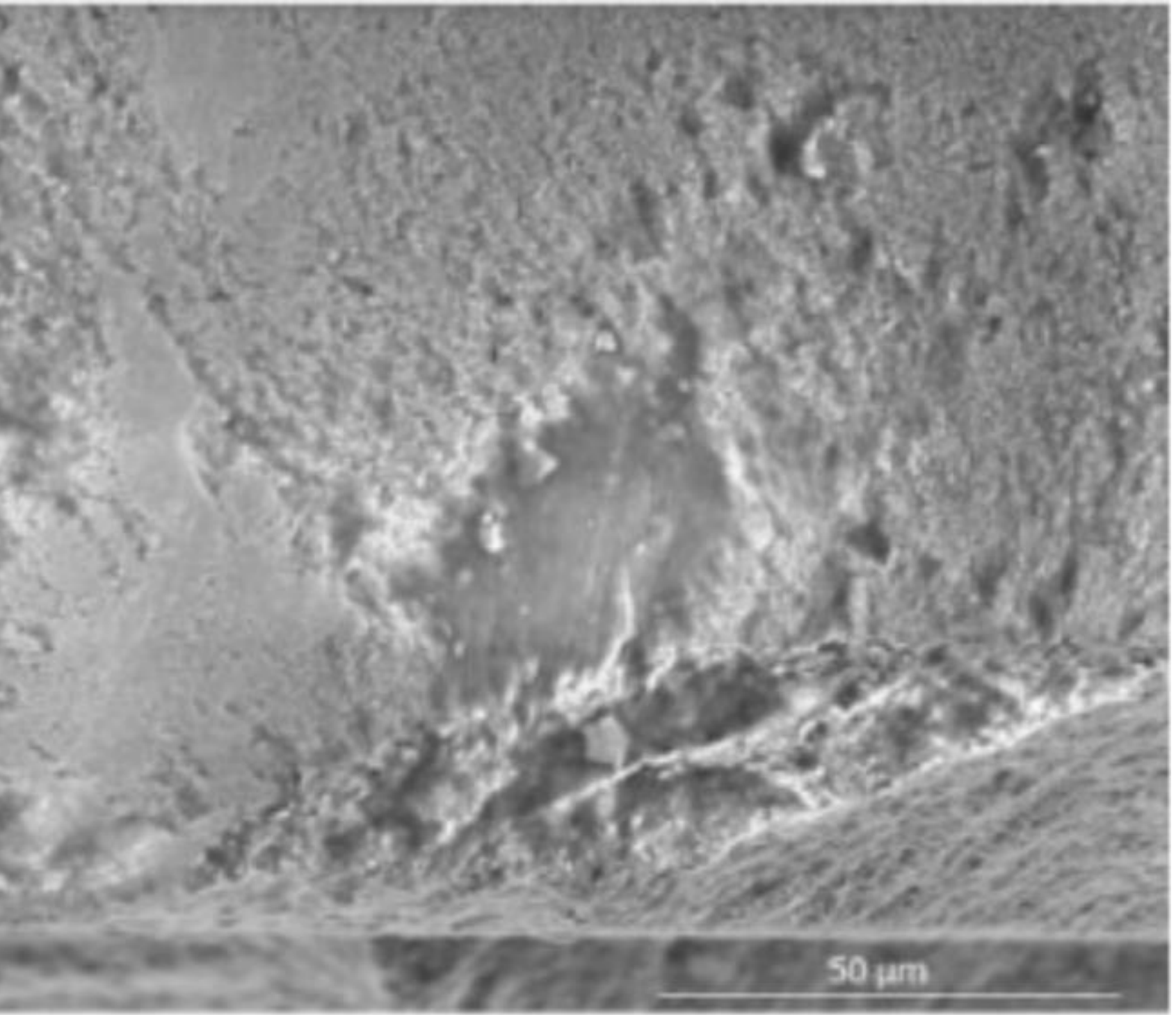


Figure 2: 3D-printed sample showing void surrounded by porosities



Conclusion

Milling zirconia from preformed dense blocks ensures homogeneity in microstructure and reduces the risk of internal defects with consistently high flexural strength. The flexural strength of 3D-printed zirconia is improving but is variable in material composition due to challenges in achieving uniform density. The layer-by-layer fabrication process can introduce microstructural defects, and sintering techniques can affect the overall strength. Ongoing research aims to improve discrepancies in yttria compositions, optimizing formulations for 3D printing and perfect sintering and post-processing techniques, which could increase flexural strength. As both technologies advance, the differences between 3D-printed and milled zirconia will likely diminish. Advancements in fabrication techniques are closing the gap. For now, milled zirconia is the ‘gold standard’ in terms of strength, availability, and well-established processing protocols, while 3D printing offers greater potential for advancement.

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