Review Article

Received: October 29, 2024
Revised: December 24, 2024
Accepted: January 3, 2025

Corresponding Author:
Thanasak Rakmanee, Division of Restorative Dentistry, Faculty of Dentistry, Thammasat University, Pathum Thani 12120, Thailand
E-mail: rthanasa@tu.ac.th

How Do CAD/CAM Hybrid Materials Perform Under Cyclic Fatigue and High Occlusal Loads? A Mini-review Article

Pacharaporn Pattanasukwasan[1], Thanasak Rakmanee[1], Nantawan Krajangta[1], Keiichi Hosaka[2], Awiruth Klaisiri[1]

[1]Division of Restorative Dentistry, Faculty of Dentistry, Thammasat University, Thailand
[2]Department of Regenerative Dental Medicine, Graduate School of Medical and Dental Sciences, Tokushima University, Japan

Abstract

The rapid advancement of computer-aided design and manufacturing (CAD/CAM) technology has transformed restorative dentistry, offering materials that combine esthetic quality with mechanical durability for indirect restorations. This mini-review evaluates the fatigue resistance and fracture behavior of CAD/CAM hybrid materials, particularly under cyclic loading and high occlusal forces. The analysis encompasses both subtractive (milling) and additive (3D printing) manufacturing methods, emphasizing each method's advantages and limitations. Hybrid materials, such as polymer-infiltrated ceramic networks (e.g., Vita Enamic®), high-density resin composites (e.g., Cerasmart®), and laser-sintered composites (e.g., Edelweiss CAD/CAM BLOCK®), are discussed in terms of their mechanical properties, including flexural strength, hardness, and resilience under fatigue.

Data from *in vitro* studies indicate that hybrid materials maintain high durability under static and cyclic fatigue conditions when fabricated at optimal thicknesses (1.0-1.5 mm), withstanding forces well beyond typical masticatory loads. These properties make hybrid ceramics suitable for minimally invasive restorations that preserve tooth structure and minimize wear on opposing dentition. However, thinner restorations (≤0.8 mm) demonstrate increased susceptibility to fracture under high occlusal forces, particularly in patients with bruxism. The review underscores the need for standardized fatigue testing protocols that mimic clinical conditions more accurately to improve predictive validity.

Keywords: CAD/CAM, cyclic fatigue, fracture resistance, hybrid materials

Introduction

Computer-aided design and manufacturing (CAD/CAM) technology is extensively used in dentistry for the fabrication of indirect fixed prostheses, including veneers, onlays, crowns, bridges, and implant-supported restorations. This technology encompasses both subtractive (milling) and additive (3D printing) manufacturing methods. Subtractive milling, known for reducing fabrication time, can lead to material waste, tool wear, and marginal chipping, particularly in thin restorations.(1) In contrast, 3D printing builds models layer by layer, minimizing waste and enabling the creation of intricate details such as undercuts. However, both methods require substantial investments in equipment, specialized software, and training, alongside strategic material selection to balance strength, esthetics, biocompatibility, and cost.(1) Milling machines are categorized into chairside and laboratory systems, each employing four- or five-axis milling strategies based on material complexity and requirements. Chairside milling facilitates in-office fabrication after scanning the patient's teeth, eliminating the need for temporization and additional appointments, while delivering highly customized restorations tailored to the patient's anatomy and esthetics. Laboratory milling, by contrast, utilizes more advanced equipment for fabricating complex restorations or using materials unsuitable for chairside processes.(2) Additive manufacturing (3D printing) in dentistry offers versatility, with key techniques including powder bed fusion (PBF), fused deposition modeling (FDM), and light/laser curing processes like stereolithography (SLA), digital light processing (DLP), and photo jet (PJ). These methods predominantly use tooth-colored ceramic and resin materials, enhancing the esthetics and functionality of the final restorations.(3)

CAD/CAM esthetic dental materials include glass ceramics, resin composites, and hybrid ceramics. Glass ceramics are highly valued for their strength, hardness, biocompatibility, and color stability. Among these, silica-based ceramics are the most common, while polycrystalline ceramics often incorporate zirconium for increased durability.(2) However, glass ceramics can be brittle, making them more susceptible to chipping or fracture under heavy occlusal forces or during milling. Their limited flexural strength can also restrict their use in restorations subjected to high stress. Resin composites, composed of an organic resin matrix and inorganic fillers, offer flexibility but still face challenges with color stability and long-term durability, despite improvements in filler technology. To overcome these limitations, hybrid ceramics have been developed, combining the properties of both ceramics and resin composites.(3-5) CAD/CAM resin matrix ceramics address this gap by blending the reparability and low abrasiveness of composites with the high flexural strength and low elastic modulus of ceramics. This combination enables stress absorption similar to dentin, reducing abrasion on opposing teeth and enhancing restoration longevity.(3-5) Hybrid ceramics also offer practical advantages, such as shorter milling times, extending the lifespan of milling tools. Additionally, they do not require post-milling processes like sintering or crystallization, thereby streamlining the fabrication process and increasing workflow efficiency.(6)

One example of a hybrid material is the polymer-infiltrated ceramic network (PICN) known as Vita Enamic® (Vita Zahnfabrik, Germany). This material consists of an 86% sintered ceramic matrix infiltrated with 14% polymer by weight, providing a combination of ceramic strength and polymer flexibility. Vita Enamic® is widely used in minimally invasive restorations, including veneers, crowns, inlays, onlays, and implant-supported crowns. Studies highlight its favorable mechanical properties, making it particularly suitable for clinical applications that require high wear resistance and minimal tooth reduction. Another prominent hybrid material is Cerasmart® (GC Corporation, Japan), a high-density resin composite containing 71% alumina-barium-silicate nanoparticles. Cerasmart® has an elastic modulus of 10.0 GPa and a Vickers hardness of 64.1 HV, which is lower than Vita Enamic® (28.5 GPa / 189.8 HV).(7,8) Despite its comparatively lower hardness, Cerasmart® is favored for its high marginal integrity and strength. A study by Suksuphan *et al.,* confirmed its excellent marginal adaptation and fracture resistance, supporting its clinical reliability.(4) Edelweiss CAD/CAM BLOCK® (Edelweiss Dentistry Products, Austria) is another innovative hybrid material, composed of 82% filler by weight, including barium dental glass within a Bis-GMA hybrid matrix. Created through a patented laser sintering and vitrification process, this material exhibits a flexural strength of 200 MPa, a compressive strength of 550 GPa, a flexural modulus of 20 GPa, and a surface hardness of 100 HV. Edelweiss® also contains zinc oxide nanoparticles and fluoride, adding antibacterial properties.[9] While these materials are predominantly fabricated through milling, new options like VaseoSmile Crown plus® are emerging. VaseoSmile Crown plus® is a pioneering 3D-printed hybrid material that combines silanized dental glass, methyl benzoylformate, phosphine oxide, and 30-50% inorganic filler with particles of 0.7 µm, expanding the potential applications of hybrid dental materials.[4]

Fracture analysis and fatigue testing of hybrid dental materials

Preserving tooth structure and ensuring adequate thickness in restorative materials are essential for the longevity and durability of dental restorations. Normal masticatory forces generally range between 9 and 180 N, with an average force of less than 70 N applied for 0.25-0.33 seconds per cycle.[10,11] However, studies indicate that bruxism patients can exert much higher forces, ranging from 777.7±78.7 N to 1692 N.[12] Observations over three nights with 10 bruxism patients revealed an average nocturnal bite force of 220.6±127.5 N, sustained for an average of 7.1±5.3 seconds.[13] To withstand such forces, manufacturers recommend specific minimum thicknesses for hybrid materials: 1.5 mm for Cerasmart® and Edelweiss® and 1.0 mm for Vita Enamic®.[4,9] Mohamed Alghauli *et al.,* categorized restorative materials by thickness as ultrathin (0.3-0.6 mm), thin (0.5-0.8 mm), and thick (0.8-1.5 mm), offering additional guidance on appropriate application.[14]

Research by Suksuphan *et al.* examined the fracture resistance of Cerasmart®, Vita Enamic®, and Varseosmile® crowns at thicknesses of 0.8, 1.0, and 1.5 mm. Their findings showed that Cerasmart® crowns could withstand forces up to 2000 N, whereas Vita Enamic® crowns fractured at 0.8 mm. Varseosmile® crowns fractured at a slightly lower force of 1480.3±226.1 N at 0.8 mm.[4] Similarly, Zamzam *et al.,* evaluated the failure behavior of 1.5 mm occlusal veneers made from Vita Enamic®, IPS e.max CAD®, and Bruxzir® using Panavia F2.0® cement. Bruxzir® demonstrated the highest failure load (843.1±141.5 N), followed by IPS e.max CAD® (493.21±102.24 N) and Vita Enamic® (499.6±123.1 N), aligning with finite element analysis predictions.[15]

Schlenz *et al.,* studied fatigue damage in 1.5 mm monolithic CAD/CAM hybrid crowns, including composites like Lava Ultimate®, Cerasmart®, and Brilliant Crios®, as well as PICN (Vita Enamic®) and LDS ceramics (IPS e.max CAD®). Under high masticatory forces (50-500 N) at 2 Hz over 1 million cycles, all crowns survived fatigue damage in occlusal contact areas without catastrophic failure. PICN and LDS ceramics exhibited the largest damage-free areas, especially when light-cured luting cement was used.[16]

Velho *et al.,* investigated the fatigue behavior of Vita Enamic® and IPS e.max CAD® using step-stress loading with Multilink Automix® cement on dentin-like substrates. Specimens were tested at 20 and 2 Hz with a starting load of 200 N and step increments of 100 N for 10,000 cycles per step. Results showed no significant differences in fatigue load or failure cycles between Vita Enamic® (20 Hz: 1127 N, 102,667 cycles; 2 Hz: 1120 N, 102,000 cycles) and IPS e.max CAD® (20 Hz: 980 N, 88,000 cycles; 2 Hz: 900 N, 80,000 cycles).[17]

The clinical outcomes of hybrid dental materials

Oudkerk *et al.,* conducted a prospective clinical study over a period of 5 years, evaluating the intraoral wear of PICN CAD-CAM composite restorations used in severe tooth wear treatment through *ex vivo* 3D profilometry examinations. Despite the presence of clinical signs of bruxism, the PICN material demonstrates a low wear process, making it a suitable material for the One-step No-prep procedure. Restoration success and survival rates at 5 years were 90.62% and 99.48%, respectively.[18]

Conclusions

The limitations of this review. For instance, this review focuses solely on fracture strength, while other properties should also be considered when selecting materials for clinical use. Collectively, these studies indicate that CAD/CAM hybrid materials can endure forces exceeding normal masticatory loads (585-880 N).[19,20] These findings suggest that hybrid dental materials offer promising clinical durability, although fracture resistance may vary depending on the specific material and thickness. Clinically, CAD/CAM hybrid materials perform well under static and cyclic fatigue, particularly at optimal thicknesses (1.0-1.5 mm), making them suitable for minimally invasive restorations. They also preserve the enamel of opposing teeth, although they may wear slightly faster themselves.[21] However, thinner restorations (≤0.8

mm) carry a higher fracture risk under significant occlusal forces.

Accurate simulation of the oral environment is essential for fatigue testing to yield reliable predictions about long-term performance. *In vitro* studies must use models that replicate clinical conditions closely. Currently, limited research examines cyclic fatigue in CAD/CAM hybrid crowns at different thicknesses. Future clinical research should focus on developing guidelines for bruxism patients to enhance the durability and mechanical wear resistance of occlusal restorations, ultimately ensuring optimal patient outcomes.

References

1. Van Noort R. The future of dental devices is digital. Dent Mater. 2012;28(1):3-12.
2. Skorulska A, Piszko P, Rybak Z, Szymonowicz M, Dobrzyński M. Review on polymer, ceramic and composite materials for CAD/CAM indirect restorations in dentistry—application, mechanical characteristics and comparison. Materials (Basel). 2021;14(7):1592.
3. Tian Y, Chen C, Xu X, Wang J, Hou X, Li K, *et al.* A review of 3D printing in dentistry: technologies, affecting factors, and applications. Scanning. 2021;2021:9950131. doi: 10.1155/2021/9950131.
4. Suksuphan P, Krajangta N, Didron PP, Wasanapiarnpong T, Rakmanee T. Marginal adaptation and fracture resistance of milled and 3D-printed CAD/CAM hybrid dental crown materials with various occlusal thicknesses. J Prosthodont Res. 2024;68(2):326-35.
5. Garoushi S, Barlas D, Vallittu P, Uctasli M, Lassila L. Fracture behavior of short fiber-reinforced CAD/CAM inlay restorations after cyclic fatigue aging. Odontology. 2024;112(1):138-47.
6. Schlichting LH, Maia HP, Baratieri LN, Magne P. Novel-design ultra-thin CAD/CAM composite resin and ceramic occlusal veneers for the treatment of severe dental erosion. J Prosthet Dent. 2011;105(4):217-26.
7. Lawson NC, Bansal R, Burgess JO. Wear, strength, modulus and hardness of CAD/CAM restorative materials. Dent Mater. 2016;32(11):e275-e283.
8. Bajraktarova-Valjakova E, Korunoska-Stevkovska V, Kapusevska B, Gigovski N, Bajraktarova-Misevska C, Grozdanov A. Contemporary dental ceramic materials, a review: chemical composition, physical and mechanical properties, indications for use. Open Access Maced J Med Sci. 2018;6(9):1742-55.
9. Edelweiss-dentistry. Edelweiss-dentistry. Edelweiss CAD/CAM BLOCK: Instruction for use on Edelweiss-dentistry, Hoerbranz, Austria. 2021-12.
10. DeLong R, Douglas WH. An artificial oral environment for testing dental materials. IEEE Trans Biomed Eng. 1991;38(4):339-45.
11. Lan TH, Chen PH, Fok ASL, Chen YF. Contact fracture test of monolithic hybrid ceramics on different substrates for bruxism. Dent Mater. 2022;38(1):44-56.
12. Reddy SV, Kumar MP, Sravanthi D, Mohsin AH, Anuhya V. Bruxism: a literature review. J Int Oral Health. 2014;6(6):105-9.
13. Koyano K, Tsukiyama Y, Ichiki R, Kuwata T. Assessment of bruxism in the clinic. J Oral Rehabil. 2008;35(7):495-508.
14. Al-Akhali M, Kern M, Elsayed A, Samran A, Chaar MS. Influence of thermomechanical fatigue on the fracture strength of CAD-CAM-fabricated occlusal veneers. J Prosthet Dent. 2019;121(4):644-50.
15. Zamzam H, Olivares A, Fok A. Load capacity of occlusal veneers of different restorative CAD/CAM materials under lateral static loading. J Mech Behav Biomed Mater. 2021;115:104290.
16. Schlenz MA, Schmidt A, Rehmann P, Wöstmann B. Fatigue damage of monolithic posterior computer aided designed/computer aided manufactured crowns. J Prosthodont Res. 2019;63(3):368-73.
17. Velho HC, Dapieve KS, Pereira GKR, Fraga S, Valandro LF, Venturini AB. Accelerated loading frequency does not influence the fatigue behavior of polymer infiltrated ceramic network or lithium disilicate glass-ceramic restorations. J Mech Behav Biomed Mater. 2020;110:103905.
18. Oudkerk J, Herman R, Eldafrawy M, Wulfman C, Ernst M, Vanheusden A, *et al.* Intraoral wear of PICN CAD-CAM composite restorations used in severe tooth wear treatment: 5-year results of a prospective clinical study using 3D profilometry. Dent Mater. 2024;40(7):1056-63.
19. Alghauli M, Alqutaibi AY, Wille S, Kern M. Clinical outcomes and influence of material parameters on the behavior and survival rate of thin and ultrathin occlusal veneers: a systematic review. J Prosthodont Res. 2023;67(1):45-54.
20. Dietschi D, Devigus A. Prefabricated composite veneers: historical perspectives, indications and clinical application. Eur J Esthet Dent. 2011;6(2):178-87.
21. Baldi A, Carossa M, Comba A, Alovisi M, Femiano F, Pasqualini D, *et al.* Wear behaviour of polymer-infiltrated network ceramics, lithium disilicate and cubic zirconia against enamel in a bruxism-simulated scenario. Biomedicines. 2022;10(7):1682.