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PMMA Denture Base Materials: A Review on Mechanical Properties of Conventional and CAD/CAM Milled Materials

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ABSTRACT

Polymethyl methacrylate (PMMA) has been utilized for the construction of dental prostheses, i.e. complete and partial dentures, artificial teeth, obturators, removable orthodontic appliances, provisional crowns, and for the repairing of broken prostheses. For completely edentulous patients, complete dentures (CDs) remain the primary treatment option. Conventional heat-cured PMMA (C-PMMA) is used to fabricate the CDs. However, this method has several disadvantages, such as inadequate mechanical properties, residual monomer content, poor stability, reduction in retention and occlusal accuracy. Recently, computer-aided design and computer-aided manufacturing (CAD/CAM) technology has been utilized for CDs fabrication. Therefore, this review makes a comparison between CAD/CAM PMMA and C-PMMA with regards to their mechanical properties i.e. fracture strength, flexural strength, flexural modulus, elastic modulus, impact strength, and hardness. The Google Scholar, PubMed/Medline, and Science Direct databases were searched for studies written in English and published between 2013 and 2026. The keywords used were conventional heat-cured PMMA dentures, heat-polymerized PMMA, CAD/CAM PMMA dentures, mechanical properties, and a combination of two or more of them. The search yielded 109 articles. Forty-nine studies have been included in this review. Results showed that the CAD/CAM PMMA dentures show superior mechanical properties compared to the C-PMMA. The use of CAD/CAM PMMA resins could increase denture longevity and improve clinical performance. Additional studies in clinical use are needed to complement these results. Therefore, further studies on the physico-chemical properties are needed to achieve a comprehensive evaluation of these materials.

1. INTRODUCTION

The last decades have shown an increased number of elderly people. Advancing age is associated with higher levels of periodontal problems, dental decay and loss of teeth, and thus an increase in the number of denture wearers (Jandial et al., 2017). Edentulism is the condition of complete or partial loss of natural teeth (Almusallam & AlRafee, 2020).

Complete denture (CD) is the first choice of treatment for edentulous patients (Saleem et al., 2011). Denture base is the foundational part of a denture that rests on the soft tissues and secures the artificial teeth on its upper surface (Klironomos et al., 2015). Denture bases are extensively fabricated from heat-cured polymethyl methacrylate (PMMA) (Mohd Farid et al., 2022). Its excellent properties, such as low cost, good aesthetics, ease of manipulation and repair, and clinically accepted oral biocompatibility make it a favorable material (Pituru et al., 2020). Good wear resistance and mechanical properties are required in PMMA to withstand the masticatory forces and wear in the oral cavity (Karthick et al., 2014). However, it has certain drawbacks like thermal shrinkage, poor mechanical and fatigue strength, dimensional changes, brittle on impact, residual monomer allergy, and porosity (Prajwala et al., 2020; Rajan et al., 2022). To further improve these properties, recent studies focus on chemical modifications and mechanical reinforcements using fibers, nanoparticles, and nanotubes (Zafar, 2020). New materials and manufacturing techniques have been introduced as possible solutions (Perea-Lowery et al., 2021). Digital dentistry has significantly changed dental practices since the 1980s (Dimitrova et al., 2022). The first attempt at developing a computer-aided design/computer-aided manufacturing (CAD/CAM) system for complete denture fabrication was made in 1994 (Anadioti et al., 2020) Goodacre et al. provided a prototype to be used as a template for digital dentures production, thus defining the principals of digital denture construction in 2012 (Tieh et al., 2022). In recent years, various restorations including implants and full dentures were produced using CAD/CAM technology (Dimitrova et al., 2022). Digital CDs are fabricated using either additive (3D printing) or subtractive (milling) processes. At the moment, the subtractive method is the most commonly used (Batisse & Nicolas, 2021). In the subtractive technique, dentures are milled from pre-polymerized discs which were fabricated under HTHP (Abualsaud & Gad, 2022). Fabrication of dentures by CAD/CAM has significant advantages over the conventional technique, such as reduced clinical visits and laboratory procedures, and records patient clinical data (El-Shaheed et al., 2022; Vashisht & Arora, 2020). Therefore, the goal of this review is to review the literature which reports on comparative studies of C-PMMA and CAD/CAM PMMA denture bases with regard to their composition, properties and fabrication techniques.

2. Polymeric Denture Base Materials

Since 1946, 98% of denture bases were fabricated from MMA polymers (or copolymers) (Duymus, Ozdogan, Ulu, & Ozbayram, 2016). Other polymers used include vinyl acrylic, polystyrene, nylon, vinyl styrene, epoxy, polycarbonate, silicones, polyurethane, butadiene reinforced acrylics, and rubber reinforced acrylics. The use of dimethacrylate monomers-based systems was limited for crowns and bridges, but now includes dentures (Narayan, 2009).

In prosthodontics, PMMA powder and a mixture (liquid) of MMA and a cross-linking dimethacrylate, such as ethylene glycol dimethacrylate (EGDMA), is the most important polymer system (Bhaduri & Bhaduri, 2009). Table 1. displays the types and classes of these polymers in accordance with ISO 20795-1:2013. Type 1 Class 1 are utilized to fabricate complete and partial dentures.

Table 1: Classification of denture base polymers according to ISO 20795-1:2013

Type	Class	Description
1	1	Heat-polymerizable polymers (powder and liquid)
1	2	Heat- polymerizable polymers (plastic cake)
2	1	Autopolymerizable polymers (powder and liquid)
2	2	Autopolymerizable polymers (powder and liquid pour-type resin)
3	-	Thermoplastic blank or powder
4	-	Light-activated materials
5	-	Microwave-cured materials

3. Ideal Properties of Denture Base Material

The optimal materials for denture base construction should have a few key characteristics, including biocompatibility, good aesthetics, high bond strength to artificial teeth, radiopacity, ease of repair, and adequate physical and mechanical properties (Meng & Latta, 2005). Other requirements by ISO 20795-1:2013 are shown in Table 2.

Table 2: Requirements of denture base polymers according to ISO 1567-2013

Requirement	Type	
	1,3,4,5	2
Flexural strength (MPa) min.	65	60
Residual monomer (wt%) max.	2.2	4.5
Sorption (μg/mm^3) max.	32	32
Solubility (μg/mm^3) max.	1.6	8.0

4. Conventional PMMA/Heat-Cured PMMA

PMMA is a versatile polymer (Forte et al., 2021) and can be variously applied in the field of prosthodontic dentistry, such as complete and partial dentures, artificial teeth, fixed bridges and crowns (Zafar, 2020). Historically, the first utilization of PMMA as a dental device was for complete dentures construction (Kosec et al., 2018). Although various new materials have been produced, PMMA remains a popular and most frequently used material due to its versatility and reliability (Punet et al., 2015).

4.1 Composition of PMMA Type 1 and 2

The composition (in powder and liquid forms) of PMMA Types 1 and 2 is shown in Table 3. The final chemical structure of PMMA is shown in Fig. 1.

Table 3: Composition of acrylic denture base materials type 1 and 2

Material		Composition
Powder	Polymer	Polymethylmethacrylate beads
	Initiator	A peroxide such as BPO (approximately 0.5%)
	Pigments	Salts of cadmium or iron or organic dyes
Liquid	Monomer	Methylmethacrylate
	Cross-linking agent	EGDMA (approximately 10%)
	Inhibitor	Hydroquinone (trace)
	Activator*	N, N′-dimethyl-p-toluidine (approximately 1%)

*Type 2 only (Cold-cured PMMA)

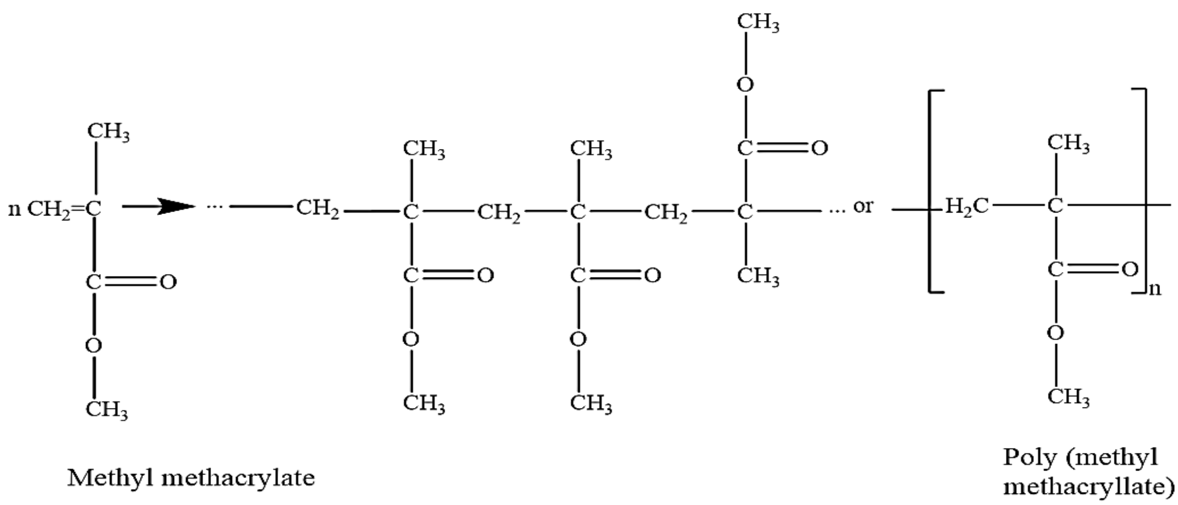

Fig. 1 Structural formula of PMMA

4.2 Properties of Acrylic Resin

4.2.1 Properties of Methyl Methacrylate (MMA)

MMA is the major constituent of the liquid. It is a clear, colorless, low-viscosity liquid, highly flammable and very susceptible to free-radical addition polymerization. It has a strong odor due to its relatively high vapor pressure at room temperature. As the powder and liquid components are mixed and activated (heat-treatment or chemically), the curing occurs through the polymerization of MMA to PMMA (McCabe & Walls, 2008). Other properties of MMA (May & Seong, 2018) are shown in Table 4.

Table 4: Properties of MMA

Property	Value
Melting point	-48ºC
Boiling point	100.3ºC
Density	0.94 g/cm^3
Polymerization shrinkage	21%
Heat of polymerization	12.900 cal/mole

4.2.2 Properties of Poly (methyl methacrylate) (PMMA)

PMMA is a high strength, stiff, exhibits excellent light transmittance amorphous thermoplastic and it is very brittle at room temperature (Rahman et al., 2023). Although it exhibits low water sorption and solubility, it has excellent dimensional stability, and ample strength. However, disadvantages include residual monomer, and poor mechanical properties, especially transverse and impact strength (Khan et al., 2022). Table 5. Displays further properties of PMMA.

Table 5: Properties of PMMA

Property	Value	Ref.
Sorption	0.30 ± 0.03 μg/mm^3	(Ulu, Yanikoglu, Sagsoz, & Ozdogan, 2021)
Solubility	0.3 ± 0.04 μg/mm^3	(Shah, Bulbule, Kulkarni, Shah, & Kakade, 2014)
Surface hardness	22.44 ± 0.98 VHN	(A. A. E. Zeidan, Abd Elrahim, Abd El Hakim, Harby, & Helal, 2022)
Surface roughness	39.72 ± 4.72 nm	(A. A. E. Zeidan et al., 2022)
Density	1.19 g/cm^3	(Youssef, 2019)
Glass transition temperature	105°C-107°C	(Youssef, 2019)
Tensile strength	68.9 MPa	(Youssef, 2019)
Flexural modulus	3,102 MPa	(Youssef, 2019)
Flexural strength	110 MPa	(Youssef, 2019)
Tensile modulus	3171 MPa	(Youssef, 2019)
Impact modulus	4.6 ± 0.07 kJ/m^2	(Srivastava et al., 2023)
Elastic modulus	3.02 ± 0.22 GPa	(A. A. E. Zeidan et al., 2022)
Fracture toughness	1.27 ± 0.002 MPa.m$^{1/2}$	(Srivastava et al., 2023)
Compressive strength	85.6 ± 6.9 MPa	(Neshati, Kouchak Dezfouli, Sadafi, & Omidi, 2021)
Impact strength	2.6 ± 0.5 kJ/m^2	(Choksi & Mody, 2016)

4.3 Polymerization Methods of PMMA Denture Base Materials

Various techniques such as microwave energy, light, and heat are applied for PMMA polymerization (Deste et al., 2020).

4.3.1 Conventional Heat Polymerization

PMMA is conventionally polymerized in a hot water bath. Several submethods are employed such as low temperature-long duration (74°C, 9 h) or high temperature-short duration (100°C, 20 min). As heat increases during the polymerization, polymer formation and conversion of monomer to polymer increase (Ozkir et al., 2018).

4.3.2 Microwave Energy

In this technique, a high frequency electromagnetic field causes oscillation of monomer molecules, generating internal heat. The increased temperature results in increased mobility of molecules, allowing for lower processing temperature, thus decrease monomer release and resulting in good accuracy (Tuna et al., 2013).

4.3.3 Light Polymerization

In light polymerized PMMA, the conventional initiator is replaced with a photoinitiator (camphorquinone), which generates free radicals when exposed to light. This material is supplied as pre-mixed paste containing PMMA fillers, silica, urethane dimethacrylate matrix, and acrylic resin monomers. Complete polymerization of PMMA requires exposure to visible light for a specific duration, after adaptation to the cast. The light-cured PMMA can be finished and polished similarly to C-PMMA (Zafar, 2020).

5. Alternative Materials to PMMA

Many efforts have been focused on developing PMMA with high strength, good dimensional stability, low levels of residual monomer, more radiopacity and enhanced resistance to Candida (Young, 2010). Polymers such as polystyrene, epoxy resin, polyamides, rubber graft copolymer, polycarbonate, nylon and vinyl acrylic, have been developed to overcome the mechanical weakness of PMMA but they are not good as PMMA (Alla et al., 2013; Hashem et al., 2014).

6. Digital (CAD/CAM) Dentures

Digitally fabricated dentures are produced by CAD/CAM technology (Abualsaud & Gad, 2022; Wedekind et al., 2021), which pertains to digital design and manufacturing (Alqutaibi et al., 2023). Subtractive such as milling or grinding of prepolymerized PMMA blanks, and additive that known as 3D printing are the two applied methods for this technique (Wedekind et al., 2021). While the subtractive approach comprises machining and milling (CAM) and laser ablation technologies, the additive approach involves 3D printing and laser melting technologies (Alageel et al., 2019).

7. CAD/CAM Milled PMMA Dentures

Mormann & Brandestinni introduced CAD/CAM technology to dentistry in 1989 in Germany (Suganna et al., 2022). Nowadays, it is extensively used in the prosthodontics field (Al Essa, 2019), and it is not only designed with the aid of computer, but also machined (milled) with high accuracy and precision (Abdulla et al., 2020). For several years, it has been uyilized to fabricate inlays, onlays, crowns, fixed partial dentures, implant abutments/prostheses, and maxillofacial prostheses. Today, it is used also for the partial and complete dentures fabrication (Bilgin et al., 2016). Compared to CDs manufactured from C-PMMA, milling CDs from HTHP- polymerized PMMA discs results in material exhibits less porosity, superior properties, and similar or lower unreacted monomer release (Punset et al., 2022; Srinivasan et al., 2022).

7.1 Denture cost

CAD/CAM CDs requires less chairside time than conventional CDs (Srinivasan et al., 2021). In addition, clinical fees for both types were similar with significantly lower laboratory costs for CAD/CAM CDs, which resulted in lower overall costs (Arakawa et al., 2022; Jafarpour et al., 2024).

7.2 Composition of CAD/CAM PMMA

The composition of PMMA blocks for CAD/CAM dentures is PMMA with pigments as shown in Table 6.

Table 6: Composition of CAD/CAM PMMA blocks

Trade Name	Composition	Manufacturer	Ref
Pink AvaDent	PMMA ≥99% and pigments <1.0%	Global Dental Science, AZ, USA	(Atalay, Çakmak, Fonseca, Schimmel, & Yilmaz, 2021)
Pink M-PM Disc	PMMA & cross-linked polymers, dyes, residual peroxide, and MMA	Merz Dental GmbH, Lütjenburg, Germany	
Pink Polident CAD/CAM Discs	PMMA and pigments	Polident d.o.o, Volˇcja Draga, Slovenia	
Telio CAD	>98% PMMA	Ivoclar Vivadent, Schaan, Liechtenstein	(Pong, Grymak, Waddell, & Choi, 2022)

7.3 Properties of CAD/CAM PMMA

Although prepolymerized PMMA blanks heat-cured PMMA show similar properties, prepolymerized PMMA offer reduced surface roughness (de Oliveira et al., 2021). In addition, PMMA blanks polymerized under high-pressure show reduced residual monomer (Ayman, 2017).

As discussed, a highly homogeneous structure, less residual monomer, and lower porosity are features of industrial CAD/CAM PMMA. This means that the water absorption of these materials was lower than that of the hand-mixed PMMA resins.

This can explain the superior mechanical properties of CAD/CAM PMMA based polymers compared to C-PMMA resins (Reeponmaha et al., 2020). Milled CDs should be considered whenever possible for complete edentulism cases since this method presents a multitude of advantages including better retention as well as better mechanical and surface properties (Srinivasan et al., 2021). However, compared to C-PMMA resins, milled PMMA demonstrated a greater degree of color instability (Al Taweel et al., 2021).

After disinfection, CAD-CAM PMMAs exhibit increased surface hydrophobicity compared to their pre-disinfection state, and the microhardness of tested milled PMMAs was higher than that of C-PMMA (Atalay et al., 2022).

8. Mechanical Properties of C-PMMA and CAD/CAM Milled PMMA

8.1 Fracture toughness (MPa·m1$^{1/2}$)

Fracture toughness (K_{IC}) is the material's resistance to failure when a crack is present and is a fundamental mechanical property (Zhang et al., 2014). In CDs, damage tolerance reflects the denture's ability to remain intact even after crack initiation, until repair can be carried (Steinmassl et al., 2018).

Inconsistent results have been obtained from studies comparing C-PMMA with CAD/CAM PMMA, suggesting that variety of material brands significantly influences the mechanical properties. Several studies reported that CAD/CAM PMMA outperforms C-PMMA. Pacquet et al. (2019) and Kamal (2021) found that CAD/CAM PMMA (IVB and IV, respectively) exhibited significantly higher K_{IC} values than their conventional controls (PRO and AS). This superiority was attributed to the more ductile behavior of the CAD/CAM PMMA (Kamal, 2021). Similarly, Steinmassl et al. (2018) found that three CAD/CAM PMMA resins (WDD, WNu and WNc) showed significantly higher mean K_{IC} than C-PMMA resin (CAR). Furthermore, a study by Malik (2019) showed that, the highest value have been achieved by CAD/CAM PMMA (IVB), whereas L199 and AD had nearly the same value. Both AD and IVB showed no statistical difference compared with L199. Additionally, CAD/CAM PMMA and C-PMMA denture bases showed no significant differences in strength. Table 7 summarizes the studies evaluating the K_{IC} of C-PMMA and CAD/CAM PMMA denture base materials.

Table 7: Fracture toughness (MPa.m$^{1/2}$) of C-PMMA and CAD/CAM PMMA denture base materials

Reference	C-PMMA			CAD/CAM PMMA		
	Material	Mean	SD	Material	Mean	SD
(Steinmassl et al., 2018)	CAR	1.25	0.11	AD	1.04	0.10
				BDS	1.02	0.07
				VV	0.80	0.07
				WDD	1.73	0.19
				WNu	1.29	0.60
				WNc	1.31	0.09
(Pacquet et al., 2019)	PRO	1.41	0.16	IVB	2.11	0.29
(Malik, 2019)	L199	1.80	0.13	AD	1.79	0.19
				IVB	1.90	0.09
(Kamal, 2021)	AS	3.53	0.50	IV	4.18	0.95

Note. *CAR = Candulor Aesthetic Red; AD = AvaDent Digital Dentures; BDS = Baltic Denture System; VV = VITA VIONIC; WDD = Wieland Digital Dentures; WNu = Whole You Nexteeth (uncoated); WNc = Whole You Nexteeth (coated); PRO = Probase Hot; IVB = Ivobase; L199 = Lucitone 199; AS = Acrostone; IV = Ivoclar Vivadent*.

In the previous studies, most of the CAD/CAM PMMA resins showed higher K_{IC} values than C-PMMA resins. In contrast, Steinmassl et al. (2018), found that the K_{IC} values of three CAD/CAM PMMA resins (AD, BDS and VV) were lower than that of C-PMMA. The authors attributed the differences in mechanical properties to compositional factors of the resin, rather than to industrial processing. Pacquet et al. (2019) related the higher K_{IC} of CAD/CAM PMMA resins to the more ductile behavior of these materials.

Prepolymerized PMMA blanks that have superior physical and mechanical properties, are anticipated to show notable enhancement in overall performance of CAD/CAM CDs (Janeva et al., 2018). This is due to the use of PMMA blanks, which have processed under a special polymerization condition (HTHP), resulting in a highly condensed CD (Alhallak et al., 2023). The formation of longer polymer chains during this process resulting in a higher degree of conversion (DC), lower residual monomer content, and minimal material porosity (Ayman, 2017).

8.2 Flexural strength (MPa)

It is a fundamental mechanical property determining a denture material's resistance to masticatory forces, simulating the mastication-exerted forces (Gibreel et al., 2022). According to ISO 20795- 1:2013, denture base materials should exhibit a minimum FS of 65 MPa.

Arslan et al. (2018) evaluated the FS of three CAD/CAM PMMA resins (MMD, AD and PDD) and compared them with C-PMMA resin (PMD). All the CAD/CAM PMMA groups exhibited significantly higher FS values than C-PMMA. In a similar comparative study, the FS of CAD/CAM PMMA (IVB) was higher than C-PMMA (L199) (Ulmer, 2019). Same results were obtained by Prpić et al. (2020), when they compared the FS of two CAD/CAM PMMA resins (IDD and PDD) with three C-PMMA resins (IV, PAL and IDD). A similar study was conducted on two CAD/CAM PMMA (AD and TZ) and C-PMMA resins (ME). The obtained results revealed that CAD/CAM PMMA groups exhibited the higher values (Al-Dwairi et al., 2020). Furthermore, Kirad et al. (2020) reported higher FS in the CAD/CAM PMMA resin (BL) compared to C-PMMA resin (DP). Moreover, a study by Hada et al . (2021) demonstrated that the FS of CAD/CAM PMMA (L199) was considerably higher than that of C-PMMA (ACR). In agreement with the previous studies, Vásquez-Niño et al. (2021) reported that the CAD/CAM PMMA (PNS) exhibited significantly the highest values of FS in comparison with C-PMMA (VNS). This aforementioned literature align with recent studies by Adsare et al. (2024) and Yu et al. (2024), which reported statistically higher FS for CAD/CAM PMMA as compared to C-PMMA.

However, a study by Lee and Lee (2020) evaluated the FS of two different brands of CAD/CAM (VBG and IVB) and C-PMMA (L199) denture base resins. VBG showed the highest average, followed by L199, whereas, IVB had the lowest value. Similarly, Pacquet et al. (2019) compared C-PMMA (PRO) and CAD/CAM PMMA (IVB), reporting that PRO exhibited a significantly higher FS than IVB. Furthermore, another study compared the FS of CAD/CAM PMMA (MMD) and C-PMMA (AS) denture base materials, revealing that the FS of MMD was significantly lower than that of AS (Saad et al., 2018). Table 8 shows the studies that evaluated the FS of C-PMMA and CAD/CAM PMMA denture base materials.

Table 8: Flexural strength (MPa) of C-PMMA and CAD/CAM PMMA denture base materials

Reference	C-PMMA			CAD/CAM PMMA		
	Material	Mean	SD	Material	Mean	SD
(Arslan et al., 2018)	PMD	108.95	5.36	MMD AD PDD	122.47 118.32 133.43	5.54 4.66 5.90
(Ulmer, 2019)	L199	63.80	3.10	IVB	82.60	1.90
(Prpić et al., 2020)	IV PAL IDD	71.80-100.70 62.20-88.50 84.10-110.60	ND	IDD PDD	103.70-119.10 97.00-116.40	ND
(Al-Dwairi et al., 2020)	ME	93.33	8.64	AD TZ	123.11 130.67	9.47 10.48
(Kirad et al., 2020)	DP	74.70	5.02	BL	93.16	5.46
(Hada et al., 2021)	ACR	87.90	5.00	L199	105.10	2.20
(Vásquez-Niño et al., 2021)	VNS	78.40	2.99	PNS	81.99	4.01
(Adsare et al., 2024)	L199	68.63	1.14	AD	97.68	1.88
(Yu et al., 2024)	IV	95.28	5.59	THD	119.11	9.29
(Lee & Lee, 2020)	L199	95.24	3.62	VBG IVB	110.06 85.27	2.69 2.87
(Pacquet et al., 2019)	PRO	97.31	4.96	IVB	87.98	7.37
(Saad et al., 2018)	AS	116.79	24.95	MMD	94.58	5.75

Note. *L199 = Lucitone 199; IVB = Ivobase; IV = Ivoclar Vivadent; PAL = Kulzer GmbH; IDD = Interdent d.o.o; PDD = Polident d.o.o; ACR = Acron; VBG = Vipi Block Gum; VR = Vertex; ME = Meliodent; AD = AvaDent Digital Dentures; TZ = Tizian; PMD = Promolux Merz Dental; MMD = M-PM Disc Merz Dental; VNS = Veracril-New Stetic; PNS = Portux-New Stetic; PRO = Probase Hot; DP = DPI-India; BL = Bloomden; AS = Acrostone.*

The results of previous studies demonstrated that the FS values of all CAD/CAM and C-PMMA resins were higher than that required by ISO 20795-1:2013(E), except for L199, which was used by Ulmer (2019).
In general, the authors agree that the flexural strength increased due to the industrial polymerization technique of CAD/CAM PMMA blanks which were made under HTHP conditions. This process enhances the mechanical properties by reducing residual monomer and internal voids while increasing the average chain length.
Furthermore, the components and the forms of the PMMA chain are expected to influence the FS of CAD/CAM PMMA. In addition, the higher degree of polymerization (DP) is considered a key factor in the polymer's strength (Al-Dwairi et al., 2020; Arslan et al., 2018; Hada et al., 2021; Lee & Lee, 2020; Prpić et al., 2020).
In a study by Nguyen et al. (2012), the HTHP polymerization significantly improved the FS and density of all investigated composites. The SEM analysis displayed a reduction in voids number and size within the HTHP polymerized composites. However, in some studies, the C-PMMA resins showed higher FS values than CAD/CAM PMMA resins. According to Saad et al. (2018), increased temperature results in additional polymerization, which improves the DC and decreases the monomer content that acts as a plasticizer. As a result, the polymer becomes less resilient and exhibits lower flexural strength. This explanation is in contrast with that given in a recent study, which postulated further reduction in the plasticizing effect of residual monomers, is expected to enhance the flexural properties (Al-Dwairi et al., 2020). In the study by Lee and Lee (2020), the authors claim that the differences among various CAD/CAM PMMA brands could be attributed to variations in manufacturing methods that resulted in differences in density or porosity, in addition to in the various compositions of PMMA blanks. Regarding the behaviour of IVB, the authors explain that this brand is classified as a high-impact resin that includes rubbery comonomers such as butyl acrylate, which causes dispersion of rubber inclusion. Therefore, the impact strength can be improved due to elasticity advancement; on the other hand, this can have a negative impact on the FS. The fractured patterns transformations was higher compared to other resins. The relatively low FS of the resin could be linked to ductility and fracture patterns.

8.3 Flexural modulus (MPa)

Flexural modulus (FM) measures the stiffness and rigidity of a material (Sherif et al., 2023). Although the denture's flexibility facilitates energy absorption before failure actually occurs, the rigidity ensures the even distribution of forces to the underlying structures (Nair et al., 2021). Thus, higher FM that reflects lower flexibility, is recognized as a clinical advantage (Chladek et al., 2019). According to ISO 20795-1:2013(E), the minimum FM required for a denture base material to pass the 3-point bend test is 2000 MPa (Ulmer, 2019).
Ayman (2017) investigated the FM of C-PMMA (VR) and CAD/CAM PMMA (PDD). The mean value of FM of VR was significantly lower than that of PDD. This result could be a consequence of the HTHP process, resulting in low residual MMA concentrations. A reduction in intermolecular distances and free volume results from these conditions during the process. In a study by Ulmer (2019), CAD/CAM PMMA (IVB) showed higher FM than C-PMMA (L199). Al-Dwairi et al. (2020) made a comparison between two CAD/CAM PMMA materials (AD and TZ) and C-PMMA material (ME). CAD/CAM PMMA groups showed superior FM. The authors related these findings to the polymerization method of CAD/CAM PMMA, which is processed under HTHP, given the resulting increase in the average molecular, with reductions in residual monomer amounts and internal voids. Additionally, flexural properties are expected to be improved by the accompanying reduction in residual monomer plasticization. A comparative study by Di Fiore et al. (2022) reported a higher FM for the CAD/CAM PMMA (RUT) compared to the C-PMMA (ABC). According to the authors, the improved mechanical properties of milled PMMA can be attributed to the manufacturing of the PMMA blocks, which processed under HTHP. The volumetric and shrinkage distortions are controlled by these procedures. According to similarly studies by Adsare et al. (2024) and Yu et al. (2024), C-PMMA showed significant lower FM compared to CAD/CAM PMMA.
Contrary to aforementioned studies, the findings by Hada et al. (2021) showed that, CAD/CAM PMMA (L199) and C-PMMA (ACR) denture base resins exhibited similar FM values. However, Lee and Lee (2020) evaluated the FM of two CAD/CAM PMMA (VBG and IVB) and C-PMMA (L199) denture base resins. The VBG showed the highest average, followed by L199, whereas IVB had the lowest value.
Table 9 shows the studies evaluating the flexural modulus of C-PMMA and CAD/CAM PMMA denture base materials.

Table 9: Flexural modulus (MPa) of C-PMMA and CAD/CAM PMMA denture base materials

Reference	C-PMMA			CAD/CAM PMMA		
	Material	Mean	SD	Material	Mean	SD
(Ayman, 2017)	VR	1550.0	60.0	PDD	2850.0	10.0
(Ulmer, 2019)	L199	1757.0	110.0	IVB	2227.0	76.0
(Al-Dwairi et al., 2020)	ME	2117.2	154.3	AD TZ	2519.6 2474.7	245.4 249.0
(Di Fiore et al., 2022)	ABC	2542.5	301.6	RUT	3435.1	346.3
(Adsare et al., 2024)	L199	1021.9	49.25	AD	1433.5	258.2
(Yu et al., 2024)	IV	1420.0	200.0	THD	2380.0	190.0
(Hada et al., 2021)	ACR	2800.0	0.0	L199	2800.0	100.0
(Lee & Lee, 2020)	L199	2706.9	50.45	VBG IVB	3259.9 1842.7	15.42 59.06

Note. *L199 = Lucitone 199; IVB = Ivobase; ACR = Acron; ABC = Candulor Aesthetic Blue Clear; RUT = Ruthinium; VBG = Vipi Block Gum; VR = Vertex; ME = Meliodent; AD = AvaDent Digital Dentures; TZ = Tizian.*

Clinically, the higher FM value may make possible the fabrication of thinner denture base while maintaining the mechanical properties (Di Fiore et al., 2022).

In the previous studies, CAD/CAM PMMA resins showed higher FM than C-PMMA resins. The values of these resins fall within the requirements of ISO 20795-1:2013(E). However, in the study by Lee and Lee (2020), the FM of IVB was lower than those of C-PMMA (L199) and fell below the minimum ISO thresholds. The authors associated the differences among different brands of CAD/CAM PMMA resins with different density or porosity due to different manufacturing processes, in addition to the difference in the components of CAD/CAM PMMA blocks.

These findings have been attributed to the fabrication method, were CAD/CAM PMMA blocks are polymerized under HTHP. These procedures control the volumetric and shrinkage distortions, increase the average molecular weight, decrease the intermolecular distances, internal voids and residual MMA. In addition, the improvements in flexural properties are expected to occurred duo to accompanying reduction in the plasticizing effect of residual monomer (Al-Dwairi et al., 2020; Ayman, 2017; Di Fiore et al., 2022)

Moreover, the literature indicated that the polymerization under HTHP improves the monomer conversion, and thus decreases free monomers and porosity. It also increases crosslinking between polymer chains while reducing the intermolecular distances and the free volume, therefore enhancing mechanical properties (Iwaki et al., 2020; Murakami et al., 2013).

8.4 Elastic modulus (MPa)

Materials with a higher elastic modulus exhibit a greater rigidity (Azmi et al., 2022). Thinner denture base can be fabricated form material with high modulus of elasticity, which exhibited higher elastic deformation resistance (Sherif et al., 2023).

A comparative study evaluating the elastic modulus of C-PMMA (ARC) and CAD/CAM PMMA (AD) materials. The results showed significantly higher value for AD (Srinivasan et al., 2018). Similarly, Steinmassl et al. (2018) compared C-PMMA denture base (CAR) with six commercially available CAD/CAM denture base materials (AD, BDS, VV, WDD, WNu and WNc). They reported that CAR exhibited a comparatively low mean elastic modulus, with all CAD/CAM groups (excluding AD and WDD) showing highly significant increases in mean elastic moduli ($p < 0.01$). Furthermore, Zeidan et al. (2022) evaluated the elastic modulus of C-PMMA (VR) and CAD/CAM PMMA (AD), revealing a significant difference where the AD group exhibited the highest mean value.

Conversely, Vásquez-Niño et al. (2021) have reported lower elastic modulus values for CAD/CAM PMMA (PNS) compared to C-PMMA (VNS). Table 10 shows the studies that evaluated the elastic modulus of C-PMMA and CAD/CAM PMMA denture base materials.

Table 10: Elastic modulus (MPa) of C-PMMA and CAD/CAM PMMA denture base materials

Reference	C-PMMA			CAD/CAM PMMA		
	Material	Mean	SD	Material	Mean	SD
(Srinivasan et al., 2018)	CAR	3900.0	200.0	AD	4100.0	200.0
(Steinmassl et al., 2018)	CAR	3570.2	450.8	AD BDS VV WDD WNu WNc	4649.12 4606.4 4569.2 4009.95 4921.1 4777.01	1110.9 325.9 267.4 200.0 87.9 110.7
(A. A. E. Zeidan et al., 2022)	VR	3017.16	215.32	AD	3240.06	61.23
(Vásquez-Niño et al., 2021)	VNS	2224.4	168.1	PNS	2125.4	57.1

Note. *VR = Vertex; AD = AvaDent Digital Dentures; CAR = Candulor Aesthetic Red; BDS = Baltic Denture System; VV = VITA VIONIC; WDD = Wieland Digital Dentures; WNu = Whole You Nexteeth (uncoated); WNc = Whole You Nexteeth (coated); VNS = Veracril-New Stetic; PNS = Portux-New Stetic.*

All CAD/CAM PMMA resins, except for the PNS group, showed higher elastic modulus values than C-PMMA resins. According to Zeidan et al. (2022), the achieved DP influenced the elastic modulus. This explanation is in line with Chen et al. (2022), who reported that as the DP of the molecular chain increased, the strength and elastic modulus increased. The improvement in elastic modulus has also been associated with the incorporation of additives (Alzayyat et al., 2022; Steinmassl et al., 2018). More recently, Babeer (2025) attributed the superior elastic modulus to the manufacturing process of CAD/CAM PMMA blanks, which are pre-polymerized under HTHP. This process results in a polymer structure with high density and cross-linking, containing minimal residual monomer and porosity, which are common structural defects in C-PMMA.

8.5 Impact strength (kJ/m^2)

Impact strength measures the material's ability to resist sudden high levels of force (Adsare et al., 2024). Denture breakage may result from impact failure due to accidental drop onto a hard surface (Yu et al., 2024).

According to Saad et al. (2018) C-PMMA (AS) demonstrated significantly lower impact strength compared to CAD/CAM PMMA (MMD) denture base materials. Similarly, Kirad et al. (2020) found that CAD/CAM PMMA (BL) achieved the highest values compared to C-PMMA resin (DP). Furthermore, a comparative assessment of two CAD/CAM PMMA (AD and TZ) and C-PMMA (ME) displayed substantially values for both CAD/CAM groups (Al-Dwairi et al., 2020). Table 11 summarizes the studies that evaluated the impact strength of C-PMMA and CAD/CAM PMMA denture base materials.

Table 11: Impact strength (kJ/m^2) of C-PMMA and CAD/CAM PMMA denture base materials

Reference	C-PMMA			CAD/CAM PMMA		
	Material	Mean	SD	Material	Mean	SD
(Saad et al., 2018)	AS	23.25	7.76	MMD	61.88	17.10
(Kirad et al., 2020)	DP	8.45	0.94	BL	15.63	2.51
(Al-Dwairi et al., 2020)	ME	14.76	2.11	AD TZ	24.56 29.56	2.63 6.94

Note. AS = Acrostone; MMD = M-PM Disc Merz Dental; DP = DPI-India; BL = Bloomden; ME = Meliodent; AD = AvaDent Digital Dentures; TZ = Tizian.

All CAD/CAM PMMA resins exhibited higher impact strength values than C-PMMA resins. Saad et al. (2018) attributed the elevated impact strength to the polymerization of the CAD/CAM PMMA blanks under high-pressure. This aligns with the findings of Al-Dwairi et al. (2020), who related the improved performance to the unique processing method, where high temperature and pressure are applied during polymerization. Furthermore, Kirad et al. (2020) concluded that the higher impact strength of CAD/CAM specimens is correlated with a higher DP, which is a major factor determining resin strength. A highly condensed resin mass with minimal porosities is achieved, because the CAD/CAM pucks are pre-polymerized to a very high degree using more sophisticated equipment than conventional methods. As noted by Longkumer et al. (2025), this improvement is a direct consequence of the reduced internal porosity and absence of processing defects in CAD/CAM PMMA, which otherwise act as stress concentrators in C-PMMA.

8.6 Hardness (MPa)

Hardness measures the material's resistance to localized plastic deformation when subjected to indentation or abrasion (Srinivasan et al., 2021). Denture bases fabricated from low hardness materials are highly prone to scratch damage during mechanical brushing. Over time, this can cause plaque formation and discoloration, which compromising the clinical longevity of the denture (Prpić et al., 2020).

Ayman (2017) evaluated the hardness of CAD/CAM PMMA resin (PDD) and C-PMMA resin (VR). The PDD group revealed a significantly higher mean surface hardness than VR. Similarly, Al-Dwairi et al. (2019) investigated the differences in surface hardness between C-PMMA resin (ME) and two CAD/CAM PMMA resins (AD and TZ). The CAD/CAM groups showed the highest hardness values. Prpić et al. (2020) evaluated two CAD/CAM resins against three C-PMMA resins, determining that the CAD/CAM groups achieved the highest surface hardness. This trend is supported by Kamal (2021), who reported superior hardness for CAD/CAM PMMA (IV) compared to C-PMMA (AS). In a recent study, Zeidan et al. (2022) found a significant difference in hardness between CAD/CAM PMMA (AD) and C-PMMA (VR) denture base materials, where the AD achieved the highest value. More recently, Patel et al. (2025) similarly reported a significant difference in microhardness between CAD/CAM PMMA (VS) and C-PMMA (DPI) denture base materials, with the VS exhibiting the highest values.

In contrast to the aforementioned studies, C-PMMA (ARC) exhibited higher hardness than CAD/CAM PMMA (AD), but the difference was not statistically significant (Srinivasan et al., 2018). Similarly, no statically significant difference was found between C-PMMA (PRO) and CAD/CAM PMMA (IVB) materials (Pacquet et al., 2019). Table 12 summarizes the studies evaluating the surface hardness of C-PMMA and CAD/CAM denture base materials.

Table 12: Hardness (MPa) of C-PMMA and CAD/CAM PMMA denture base materials

Reference	C-PMMA			CAD/CAM PMMA		
	Material	Mean	SD	Material	Mean	SD
(Ayman, 2017)	VR	13.22	0.88	PDD	22.41	1.50
(Al-Dwairi et al., 2019)	ME	177.4	3.04	AD TZ	202.00 194.2	3.24 10.59
(Prpić et al., 2020)	IV PAL IDD	130.2-138.1 113.95-123.2 126.6-134.1	ND	IDD PDD	142.4-147.04 142.4-147.04	ND
(Kamal, 2021)	AS	46.80	1.30	IV	50.60	1.20
(Zeidan et al., 2022)	VR	220.1	9.6	AD	286.2	33.8
(Srinivasan et al., 2018)	CAR	232.00	15.00	AD	221.00	14.00
(Pacquet et al., 2019)	PRO	190.8	3.9	IVB	189.4	14.5
(Patel et al., 2025)	DPI	233.3	24.52	VS	308.42	25.5

Note. *IV = Ivoclar Vivadent; PAL = Kulzer GmbH; IDD = Interdent d.o.o; PDD = Polident d.o.o; VR = Vertex; AD = AvaDent Digital Dentures; CAR = Candulor Aesthetic Red; PRO = Probase Hot; IVB = Ivobase; AS = Acrostone; ME = Meliodent; TZ = Tizian; VS = VinciSmile.*

All CAD/CAM PMMA resins, except the AD and IVB, showed higher hardness values than C-PMMA materials. This may be attributed to the polymerization process of CAD/CAM PMMA, which occurs under HTHP. In addition, the incorporation of fillers reduces polymerization shrinkage and increases the hardness values (Ayman, 2017). In line with this, Nguyen et al. (2012) reported a significant increase in both hardness and density of dental resin composites polymerized under HTHP. SEM observations also revealed fewer and smaller voids. According to Prpić et al. (2020), high-pressure promotes longer polymer chains formation and results in increased DC.

Furthermore, mechanical properties, including surface hardness, are enhanced by the presence of inorganic fillers and elevated polymerization temperatures in CAD/CAM PMMA. As reported by Zeidan et al. (2022), reduced residual monomer content minimizes the plasticizing effect, thereby enhancing hardness. Moreover, homogenous heating of PMMA improves monomer conversion, reduces residual monomer plasticization, and consequently increases surface hardness (Al-Dwairi et al., 2019).

2. CONCLUSION

PMMA resins intended for denture base construction must exhibit adequate mechanical strength. To improve the mechanical properties of PMMA acrylics, many modifications have been applied. The improvement may be achieved through up by the introduction of CAD/CAM PMMA resins. Based on the available literature, it can be concluded that CAD/CAM PMMA resins exhibit structurally superior mechanical properties compared to C-PMMA resins; particularly in terms of fracture strength, flexural strength, flexural modulus, elastic modulus, impact strength, and hardness. However, besides the manufacturing techniques, these mechanical advantages are heavily dictated by the chemical composition and cross-linking density of CAD/CAM PMMA resins. Consequently, this review provides clear insights about the manufacturing process and resin composition as a guide for a deeper understanding of advanced denture base resins.

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