

Exploring Best Fit-Dental Materials for CAD/CAM

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INFORMATION

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ABSTRACT

With the extensive research and investment in CAD/CAM technology, the available options of machinery, as well as dental materials, are growing day by day. To find the best fit, one must have a thorough understanding of what material and process are apt for a particular situation, and one should also keep oneself updated with the latest findings and products provided by various manufacturers. With the new technology coming in, cost becomes a significant factor in deciding the right material. There are plenty of options, but the question is 'are these options scalable in terms of manufacturing at scale and low cost?'. We would try to explore the options available in the market and the ones that are in the pipeline in the document. Three factors affecting the decision are strength, aesthetic quality and cost. Necessity is to find that fine balance among these three as per the clinical situation.

1. Introduction

CAD/CAM Dentistry refers to utilising the intelligence and precision of a computer in designing and manufacturing a customised patient-specific dental fixture or device [1]. While Dentistry is as ancient as the human civilisation and CAD/CAM has its roots to ancient Egypt, Greece and Rome when Leonardo Di Vinci had used modern graphics convention in his works, the amalgamation of both happened in the 1970s. The utilisation of the CAD/CAM technology in dentistry marks its start in 1971 with Dr Duret as he used optical means to take an impression of abutment teeth [2]. He then forged a crown with the help of that impression using a numerically controlled machine. A commercially designed CAD/CAM system was first introduced in 1985 by Mormann, that was named as CEREC [3]. Currently, CEREC is widely used across the globe for the fabrication of inlays, outlays, crowns and many other dental fixtures and devices. Modern CAD/CAM provides an alternate and efficient method to process fixed dental prosthesis and indirect dental restoration. It eliminates many laboratory and clinical steps involved to make the process faster and efficient. It promises esthetic and accurate restorations in quick time.

The process is mainly comprised of two things, firstly, the machining system that facilitates the scheme, secondly, the milled materials that essentially define the long-term success or failure of the system. The milling material must be damage resistant, to be polished, glazed or stained easily and most importantly milled rapidly. Enhanced systems may also be used to mill high strength ceramic materials. A few systems are capable of milling materials like Titanium or noble or base material. As a final step, the milled framework needs to be veneered using porcelain powder by hand or pressed with prefabricated ingots [4].

Everyday advancing digital fabrication techniques and development of stronger and with enhanced characteristics, ceramic materials have provided practitioners

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with multiple options and ability to combine durability with aesthetics. But with increasing options, it becomes difficult to determine the best fit for a particular situation. Different CAD/CAM materials have different material properties, clinical indications and processing techniques. All of them together defines the best use of a particular material. Thus, the practitioner must understand the properties and required processing techniques of CAD/CAM materials available. [5].

2. Different classes of materials

The first inlay fabricated by chairside CAD/CAM was made with a ceramic block made of fine grain feldspathic ceramic in 1985. Different systems have been developed since then with the help of a series of development in software and hardware. Modern systems offer 3D design programs combined with improved machinery that can produce frameworks as complicated as custom lithium disilicate implant abutments. CEREC I was the first system that used feldspathic ceramics for smaller occlusal inlays. Reinforced ceramics were developed to extend the indications of restorations. Pre-crystallised stage of such reinforced ceramics is used to enable rapid milling. Crystallisation needs to be done post milling to get the mechanical strength and final colour. Next set of materials used are of resin class that is soft and less susceptible to brittle fracture. These materials are then mixed with ceramic particles to improve their mechanical properties. A ceramic network is infiltrated into resin polymers in the process to combine advantages of both materials. A few metals have also been used as a block, but these instances are rare.

2.1 Metals and alloys

Titanium and Cobalt-Chromium (Co-Cr) alloys are the most common metals used in milling Fixed Partial Dentures (FPDs). Pre-sintered form of Co-Cr alloys is used that enables faster machining and low damage to burs. Co-Cr blocks are made by compaction of Co-Cr powder by isostatic pressure. It gives soft and tender but solid metal block. Sintering the prosthetic fixture as a post-treatment improves the mechanical properties. This treatment reduces the pores and improves its properties regarding compactness. Precious metal alloys couldn't become popular due to various reasons, including high cost.

2.1.1 Usages

Lack of aesthetics is the major roadblock for widespread usage of the material. Though it is not used for achieving

abutments but is widely used in thin reconstitution. Titanium is preferred for metal implants as electrochemical corrosion is the least for Titanium. It becomes more important in cases where metal restoration has already been done. These blocks are suitable for frameworks and metal-ceramic restorations. However, metal blocks are not used in chairside CAD/CAM. A few popular blocks present in the market are Sintron produced by Amann Girrbach and Crypton produced by Dentsply [6]. The primary difference between these two is the milling process; former requires dry milling whereas later is milled with oil and water spray in a closed environment as suspended Co-Cr microparticles are toxic.

2.1.2 Implementation

Metal blocks are sintered post-producing the prosthetic framework as it requires a post milling treatment. It is basically a heat treatment process that is performed with or without external pressure depending upon the required material characteristics where a porous material reduces its porosity resulting in better compactness. Sintering causes around 10 per cent shrinking of the parts; thus, the design of the part must incorporate this to achieve exact size after the treatment.

2.2 Ceramics

Metals are strong, but they don't provide a natural appearance. The demand for natural appearance resulted in the development of ceramic restorative material. Ceramic is a composite of two or more substances in the form of glass or polycrystalline matrix. Fillers in different quantities are infused to obtain certain mechanical properties, and particles (glassy or crystal) or modified atoms are doped to obtain stabilised polycrystalline structure. The glassy matrix defines the aesthetic property, greater the glass rate; more would be the translucency (diffusion of light) to best imitate the properties of enamel and dentin [7]. There is always a tradeoff between aesthetics (translucency) and strength in dental ceramics. Crystalline ceramics provide higher strength but have an opaque appearance. Such ceramics with feldspathic porcelain veneer are generally used in the bilayer restoration framework. On the other hand, predominantly glassy ceramics provide high translucency but are relatively weaker than crystalline ceramics. Based on microstructure, strength, aesthetic quality and clinical indications, ceramics are divided into three major classes such as Zirconia, Crystalline glass ceramics and Resin ceramic composites.

2.2.1 Zirconia

It is the most popular among the CAD/CAM materials used in dentistry. It was introduced around 2005, and it quickly gained popularity as it has excellent mechanical properties and is easily machinable in CAD/CAM machines. It is basically an oxide with high tensile strength, hardness and corrosion resistance. Most of the material used is obtained from Zirconate ($\text{ZrO}_2\text{-SiO}_2$, ZrSiO_4) and Baddeleyite (ZrO_2). The basic difference between them is the amount of Zirconia present in them. While Baddeleyite contains 96.5 to 98.5 per cent [8], Zirconate requires significant processing to get Zirconia. But Zirconate is significantly abundant than Baddeleyite. Zirconia (ZrO_2) presents a monoclinic structure at room temperature. It is processed at high temperature synthetically to form cubic zirconia (a cubical structure). Cubic Zirconia is harder, translucent and optically flawless.

2.2.1.1 Phases of Zirconia

Zirconia exhibit polymorphism, and it has three crystal structure or phases characterised by distinct crystallographic structures: monoclinic, tetragonal and cubic (Figure 1). Monoclinic structure characterises pure zirconia that is stable up to 1170°C . Above 1170°C tetragonal zirconia is formed, and after reaching a temperature of 2370°C , cubic zirconia starts forming. Tetragonal phase changes to monoclinic at 970°C after processing [8]. Cooling of zirconia results in a significant volume change of around 2-3% due to polymorphism. It can't be processed at high temperature as the change in volume is sufficient to exceed the fracture limit and develop cracks and fatigue in the framework. Thus, manufacturing of components from pure zirconia is complicated, stabilising oxides are added that helps in maintaining the tetragonal structure at room temperature. The transformation of the crystal structure is utilised to develop particular mechanical property of zirconia such as tenacity. It transforms from tetragonal to monoclinic between 850°C and 1000°C depending upon the magnitude of strain energy.

One of the most commonly used zirconia is Yttria. It is a stabilised form in which tetragonal phase of Zirconia is stabilised at room temperature by adding Yttria. Another main additive for zirconia is Alumina, the amount of Yttria and Alumina decides the strength and translucency.

2.2.1.2 Types of Zirconia

2.2.1.2.1 Framework Zirconia

It is used in multi-unit bridge framework for posterior

and anterior regions. It is an aesthetic alternative to Metal restorations and is being widely adopted.

Properties and indication

It is diffused with feldspathic porcelain or glass-ceramic to provide a natural appearance. It has higher alumina content around 0.25% that makes it strong and opaque. The usual composition of framework Zirconia is 3-mole percentage Yttria stabilised tetragonal Zirconia [10]. Transformation toughening provides zirconia with excellent mechanical properties. The framework zirconia expands on the application of stress which inhibits crack propagation. It has a flexural strength of 900 to 1400Mpa and fracture toughness of 5 to $9\text{MPa}/\text{m}^2$ [5].

2.2.1.2.2 Full Contour Zirconia

It is the most popular choice for moral single crowns and posterior multi-unit bridges as an alternative to FPM restorations and gold crowns.

Properties and indications

It has a low content of alumina around (0.05%) [5]. Thus, it has improved translucency that makes it more suitable as a single layer or monolithic material. Monolithic restorations are done in a single process, therefore, better suited for posterior region. Full-contour Zirconia also has 3-mole percentage Yttria stabilised zirconia. Thus, it also has fracture toughness and flexural strength like Framework Zirconia. While using monolithic Zirconia, wear of antagonist enamel was always a roadblock; this has been solved by polished zirconia that maintains a polished surface finish.

2.2.1.2.3 Cubic Zirconia

It is the most popular choice for single crowns and anterior three-unit bridges. It is a tougher alternative to glass ceramics and a more aesthetic alternative to full contour Zirconia.

Properties and indications

It has more than 5 moles per cent of Yttria and a higher proportion of cubic phase of Zirconia. This gives it translucency and makes it look more natural. Though, the aesthetic quality of cubic Zirconia is better than Full Contour Zirconia but not as good as feldspathic porcelains or glass-ceramics. The higher proportion of cubic phase also causes brittleness resulting in less resistance to crack propagation. It has a flexural strength of 500 to 700MPa , and its fracture toughness has not been measured accurately.

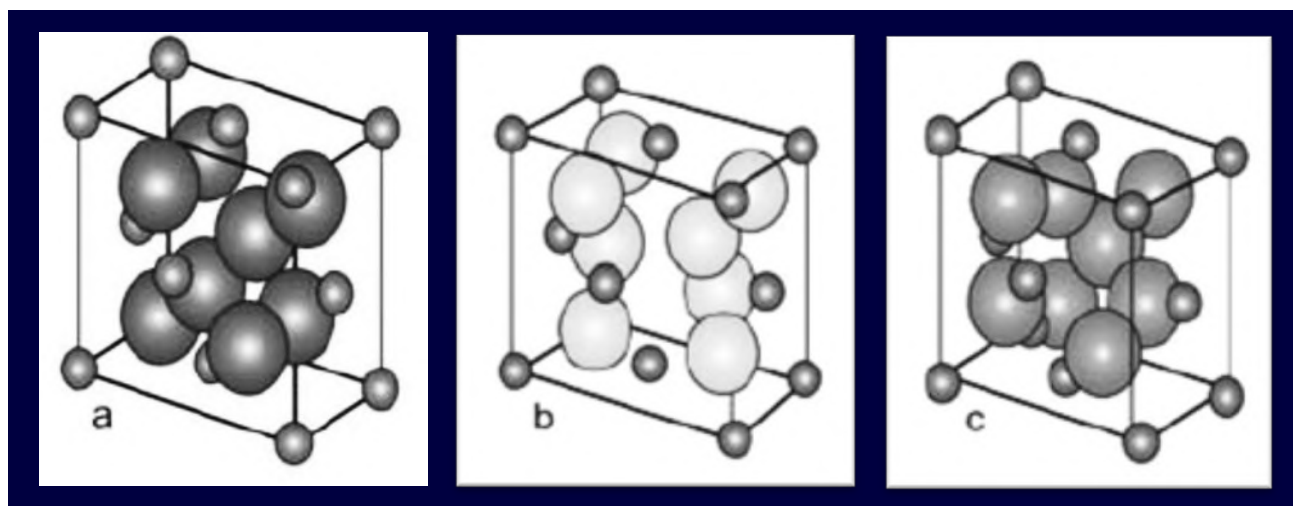


Figure 1. Zirconia crystalline structures; a. Monoclinic b. Tetragonal, and c. cubic crystal structure [9]

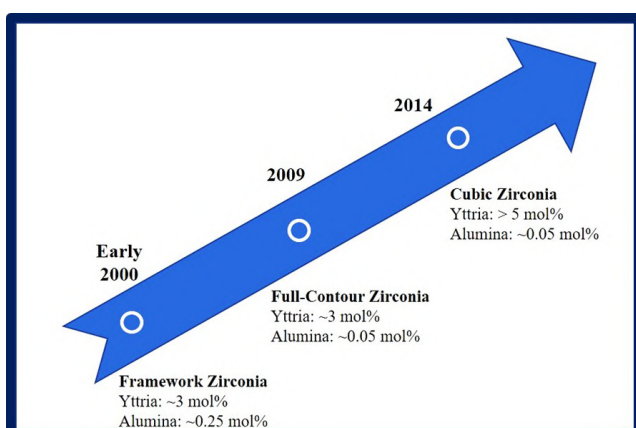


Figure 2. Evolution of Zirconia types , Time-line and Constituents [10]

The development of various types of zirconia materials are described in figure 2.

2.2.1.3 Application of Zirconia in Dentistry

There are various zirconia ceramic systems available. Yttrium cation-doped tetragonal zirconia polycrystals (3Y-TZP), magnesium cation-doped partially stabilised zirconia (Mg-PSZ) and zirconia- toughened alumina (ZTA) are the ones used till now in dentistry [10]. These materials have been used in dental posts (Figure 3.a), crown and bridges (Figure 3.b), implant abutments (Figure 3.c), and aesthetic orthodontic brackets [11].

2.2.2 Crystalline glass ceramics

Glass Ceramics have become popular because of its superb aesthetic quality and ability to bind with tooth structure. It is mostly used in the anterior regions as it does not have sufficient strength to be used in the posterior regions. It is a multiphase solid that contains finely dispersed crystalline phase with a residual glass

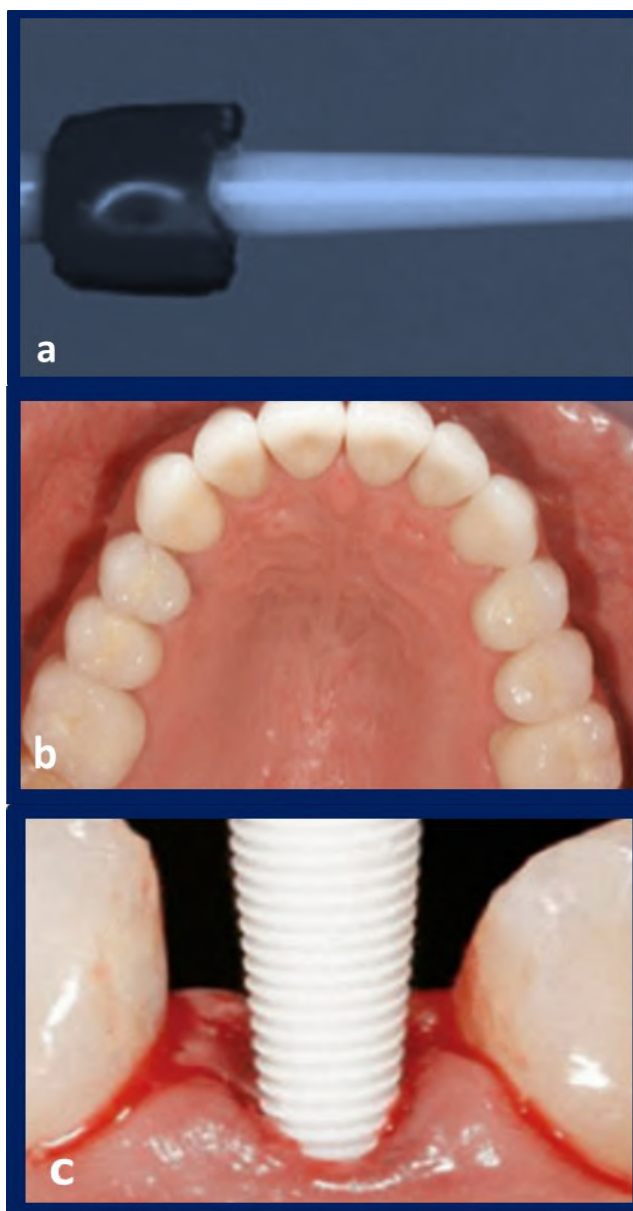


Figure 3. Zirconia-based a. Dental posts , b. Frameworks, and c. Implant [12].

phase. Controlled crystallisation of the glass is done using creaming heat treatment method to form tiny crystals evenly distributed throughout. The size of the crystals, their number and growth are controlled via temperature and time of the heat treatment process [12].

The first CAD/CAM ceramic material used by dentists was feldspathic porcelain that was followed by leucite-reinforced with better flexural strength. These became popular because of their excellent aesthetic properties and were mainly indicated for inlays and veneers. Now, it is being replaced with stronger glass-ceramics. Similar to feldspathic porcelain, glass ceramics has a glassy matrix structure that provides translucency and a crystal phase embedded in the structure that imparts mechanical properties.

2.2.3 Lithium disilicate ceramics (LDS)

LDS is available in the market in many varieties with the excellent combination of translucency and strength. Anterior single crowns and three-unit anterior bridges are made with less translucency and high strength blocks whereas, inlays, onlays and veneers are made with high translucency and low strength blocks. LDS is also an option for higher aesthetic demand and somewhat for single posterior crowns.

Properties and indications

LDS has a flexural strength of 200 to 400 MPa and fracture toughness of around 2 to 2.5 MPa/m² [13]. Initially, it was a sub-structural material that needed to be veneered with feldspathic porcelain. With certain improvements in aesthetic and mechanical properties, it became usable as a single monolithic layer. LDS has better aesthetic quality than all the Zirconia based materials and more strength than other glass-ceramics. LDS is comparatively more abrasive, so dentists polish the restoration to remove milling marks before going for sintering.

2.2.4 Leucite-based Glass Ceramics

These are formed by controlled nucleation and crystallisation of the base glass. The base glass is composed of additives that facilitate nucleation and crystallisation process in K₂O-Al₂O₃-SiO₂ system. The final step is heat treatment after which leucite crystals are precipitated containing 35 to 45 % crystal content by volume and crystal size of 1 to 5 µm [13].

Properties and indications

Leucite-based (K [AlSi₂O₆]) glass-ceramics exhibit

superior biocompatibility alongside their suitable physical, chemical and mechanical properties. They are also suitable for chair-side milling process. Leucite based products are available in different colours with different level of translucency and brightness that enables better imitation of natural teeth. Due to its excellent aesthetic quality, it is used for fabricating anterior crowns, inlays and onlays. It is also a handy material as the complete process of pre-operative condition to the fabrication of the restoration to cementation of restoration takes around 2 hours.

2.2.5 Yttrium-stabilised zirconium oxide-based ceramic

Zirconium oxide-based ceramics are mainly used in fabricating crown and bridge frameworks. It is also suitable for post, abutment and implant. Fabrication of dental restorations with Zirconium oxide is achieved through machining of dense ceramics and pre-sintered ceramics. While machining of dense ceramic is time-consuming and the required machinery and equipment are heavy, another method is developed where it is milled in a porous state using smaller and less complicated machinery.

Properties and indications

These are characterised by high fracture strength and toughness. Flexural strength measures around 900 to 1200 MPa and fracture toughness around 4 to 5 MPa/m² [13]. Restoration achieved from CAD/CAM equipment is densely sintered at higher temperatures between 1400 to 1500°C. Colouring of Zirconia based ceramics have also been made possible recently making it aesthetically more viable [13].

2.3 Resins

Resins are used as restorative as well as adhesive. Its micro retention property makes it more suitable for filling smaller cavities where other restorative materials don't hold well [14]. Conventional resins are made up of polymeric matrix reinforced by inorganic fillers like glass or glass-ceramic or oxide ceramic [15]. Currently, there are mainly three variations of resin materials available. They include Polymethyl Methacrylate (PMMA), Resin composite, and Nanoceramics

2.3.1 Polymethyl Methacrylate (PMMA)

These are made of methyl methacrylate polymers. There are no added fillers, thus resulting in lower mechanical strength. It is a thermoplastic polymer that is transparent.

Properties

It has a tender structure that enables fast and easy machining and causes minimum wear to the bur. It is used for making temporary restorations or any prosthesis that is to be used for a maximum of 1 year.

2.3.2 Resin Composites

These are matrix resins composed of monomers infused with inorganic fillers. Fillers are to improve the mechanical properties of the composite. More the quantity of the charge better is the mechanical property of the resin. Smaller load size results in improved surface finish, wear-resistance and aesthetics[16]. The composite blocks are made by thermal polymerisation under a pressure of several thousand bars. The conversion rate of these blocks in chairside machining is more than 90% as compared to 50 to 60% for other blocks [17].

Properties and indications

This is the only resin used in chairside CAD/CAM. Its wearing period is three years as compared to 1 year for PMMA. The machining for resin composites is easier and causes less wear to burs. The flexural strength of Resin composite is around 80 MPa that makes it viable for making the veneers, inlays and onlays, anterior bridges, posterior bridges, anterior crowns and posterior crowns.

2.3.3 Nanoceramics

It has similar microstructure to resin composites. It has a polymeric matrix and has ceramic nanoparticles as fillers. Fillers have sizes lesser than 100nm and constitute 80% of the weight. The fillers can be conventional ceramic, zirconia or a mixture of both.

Properties and indications

The characteristics of Nanoceramic are quite similar to the natural tooth. It has a flexural strength of 200MPa, compression of 380MPa, the elasticity of around 15GPa and abrasion of approximately 2 to 10 microns/year [6]. Nanoceramics are used for veneers, single anterior crowns, single posterior crowns, inlays/onlays, anterior bridges and posterior bridges. These are easily machinable due to its softer matrix structure, and it doesn't require any milling treatment other than make-up photopolymerisation.

2.4 Polymer Infiltrated Ceramic Network Material (PICN)

It has a hybrid structure with a matrix of polymer and

ceramic penetrating into each other. It has properties of ceramic as well as polymer. The fabrication process requires two steps, first being the production of a pre-sintered ceramic network that is porous and then conditioned with a coupling agent. Secondly, it is penetrated with a polymer [6].

Properties and indications

It has characteristics similar to dentin as its abrasion, elasticity, and flexural strength is much similar to dentin. It is more wear-resistant than resin composite due to the ceramic network present in the structure. This material is quite recent; thus, the exact characteristics are not defined. However, it has looked promising, and research has been going on for further improvements. Currently, it is used for fabricating veneers, inlays/onlays, single anterior crowns, posterior single crowns and implant prosthesis [6].

3. Conclusion

The new generation of CAD/CAM materials offers a plethora of options in terms of fabrication techniques as well as varying properties. While zirconia has become most popular due to its low cost and viable mechanical and aesthetic properties, new materials produced by infusion techniques promises enhanced properties in terms of aesthetics as well as strength. Glass based composites are aesthetically superior and they are being imparted with better mechanical properties using additives and different treatment techniques. Materials like nanoceramics and PICN promises better quality in terms of both strength and natural look. For inlays, onlays and veneers, adhesive cementation and natural look are critical factors as most of the materials fulfil the strength requirement. LDS and resin ceramic composites are best suited for them as they provide good aesthetic quality with greater machinability, thus reducing the chair time.

Similarly, for anterior crowns, LDS provides the most suitable combination of mechanical and aesthetic properties. Different materials are best suited for various clinical situations. However, none of these has properties for universal application. The passionate effort is being put in the research to enhance strength, aesthetics, machinability, ability to bond with other dental substrate and enhanced durability of these materials.

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