CAD/CAM MATERIALS

COMPOSITION, MECHANICAL PROPERTIES & INDICATIONS FOR USE

THE MATERIALS AVAILABLE TO CLINICIANS PERFORMING IN-OFFICE MILLING OF CROWN AND BRIDGE RESTORATIONS HAS EXPANDED SINCE THE EARLY DEVELOPMENT OF CAD/CAM DENTISTRY. THIS ARTICLE WILL DESCRIBE THE COMPOSITIONAL DIFFERENCES BETWEEN MATERIALS AVAILABLE FOR IN-OFFICE MILLING. PARTICULAR ATTENTION WILL BE GIVEN TO ZIRCONIA AND THE BENEFITS OF USE OF THIS MATERIAL. FINALLY, A PROTOCOL FOR BONDING ZIRCONIA SPECIFIC FOR THE CAD/CAM CLINICIAN WILL BE DESCRIBED.

How to differentiate the composition of different CAD/CAM materials

A couple brief material science concepts will help better explain the composition of CAD/CAM materials. First, all materials can be classified as metals, ceramics, polymers, or a combination of one of these 3 basic types of materials. Generally, metals are ductile (can deform prior to failure), ceramics are stiff (cannot bend without cracking) and brittle (do not deform prior to failure) and polymers are flexible (can bend without cracking).1 Within the category of ceramics, there are those which are glasses (weaker and more translucent), crystals (stronger but more opaque), and combinations of the two.

In general, CAD/CAM materials can be divided into glass ceramics, resin composites and zirconia.2-4

Glass ceramics

Glass ceramic materials have been a staple of CAD/CAM dentistry since its inception. The term glass ceramic implies that the material is a ceramic composed of a glassy phase and crystalline phase. The glass phase imparts translucency, etchability, and machinability and the crystalline phase imparts strength. Some of the original glass ceramic materials were feldspathic porcelain (ie CEREC Bloc, VITABLOC), which contain a very high content of the glassy phase. Leucite-reinforced ceramics (ie IPS Empress CAD) contained increased amount of leucite crystals which improved the mechanical properties of the material. Perhaps the most used glass ceramic materials are the lithium disilicate/metasilicate ceramics (ie IPS e.max CAD, Celtra Duo, Amber Mill, Suprinity, etc).4 These ceramics contain a very high content (around 70-80%) of lithium disilicate/metasilicate crystals, giving them impressive mechanical properties. Crystallization of these materials in a furnace is often required to increase the size of the crystals. Placing glass ceramics materials in the furnace will also help to melt the glass phase and heal any cracks introduced during milling.5

Resin composites

CAD/CAM resin composites contain a polymer matrix with reinforcing ceramic filler particles. Often they have the same composition as the resin composites used for direct composite restorations. CAD/CAM resin composite blocks will have mechanical properties superior to direct resin composites, however, as they are polymerized with high pressure and heat during fabrication.6 For the purpose of this article, resin composites will be used to describe any CAD/CAM material which contains a resin component, however, they may also be described as nano-ceramics or hybrid ceramics. An advantage of resin composite blocks is that restorations can be fabricated easier and faster than with glass ceramics. Their softness makes them easier to mill, adjust and polish.7 Additionally, they do not require crystallization. The major disadvantage of the category of materials is that they are not as strong as ceramic materials.8 Additionally, their flexibility may be disadvantageous in certain clinical situations. A high failure rate was noted with resin composite crowns on implant abutments because the resin composite crowns flex more under function than the abutment.9 Additionally, resin composite would not be indicated for partial coverage restorations in which thin walls of tooth structure remain in the preparation. Resin composites will be more likely to transfer stress to the thin wall rather than absorb the stress.10

Zirconia

Zirconia is a polycrystalline ceramic. This means that it

is entirely composed of crystals and there is no glass phase. The presence of an entirely crystalline microstructure is what imparts strength to zirconia but what also gave initial formulations of zirconia its opaque appearance. Translucency of zirconia is improved by changing the atomic arrangement within the crystals of zirconia. Atoms arranged in the cubic phase allow zirconia to be more translucent. It is a more symmetrical atomic arrangement which allows light to pass through cubic zirconia crystals in multiple directions.11 Zirconia blocks are fabricated by compressing zirconia powder into a mold. In the block form, zirconia has a chalk-like consistency because there are porosities between the powders of zirconia. After the restoration is milled, zirconia is sintered in a furnace. Sintering is fusing of these powders to eliminate the internal porosity, giving zirconia its final strength.

What are the advantages of using zirconia

Zirconia is by definition a ceramic as it is an oxide of the metal element zirconium. But zirconia behaves unlike other dental ceramics, such that the seminal paper describing the type of zirconia used in dentistry was titled "Ceramic Steel". There have been other polycrystalline ceramics used in dentistry, such as alumina (ie Procera), however, the unique property of zirconia is its ability to undergo transformation toughening. Transformation toughening occurs when cracks are initiated in a zirconia restoration through actions such as grinding with a bur, sandblasting with aluminum oxide, or biting with the patients teeth. In most ceramic materials, these cracks may propagate through the restoration eventually leading to fracture. In zirconia, these cracks may be stopped from propagating when individual crystals surrounding the crack transform to a slightly larger size and "squeeze" the crack shut. This process is known as transformation toughening.13

As mentioned previously, the evolution of dental zirconia has led to the inclusion of cubic phase zirconia to improve its translucency. Cubic phase is produced by adding various concentrations of the dopant yttria. Addition of 5 mol% yttria (5Y) will create about 50% cubic phase, addition of 4 mol% yttria (4Y) will create about 25% cubic phase, whereas, 3 mol% yttria (3Y) is the original formulation of zirconia. Inclusion of too much cubic phase, however, will limit the ability of zirconia to undergo transformation toughening. Laboratory testing has confirmed that 4Y zirconia is capable of transformation toughening while providing improved translucency, whereas most of the ability to undergo transformation toughening is lost with 5Y zirconia.13

Another advantage of zirconia is that it is wear friendly to opposing teeth. In fact, it is much less abrasive to opposing teeth than the feldspathic porcelain that was commonly used on the lingual and occlusal surfaces of porcelain fused to metal crowns. The reason that zirconia is wear friendly is attributed to its strength. Weaker ceramics, such as porcelain, will chip and roughen when opposed by enamel. This rough surface can be abrasive to opposing enamel. Zirconia does not roughen from enamel wear and therefore it will remain smooth under function.14

How to compare and interpret mechanical properties for proper use of materials for CAD/CAM restorations

When a manufacturer or dental laboratory present values of mechanical properties for a restorative material, the clinician must decide which properties are most critical and what are the thresholds for clinical use. When evaluating CAD/CAM materials, a clinically relevant mechanical property to evaluate is strength. Strength can be measured in many ways (ie flexural, compressive, tensile, etc). Even though it seems as if crowns fail when patients apply compressive biting forces, ceramics are weakest in tension and will fail from tensile stresses. Tensile stresses can originate in sharp corners on the intaglio surface of crowns, along uneven crown margins, or at the gingival embrasures of bridges.15,16

The most common method to measure strength is the flexural strength method. The flexural strength test method applies a force on the top of a ceramic specimen which causes the specimen to bend and experience tensile forces on its bottom surface. The International Standards Organization (ISO) and the American Dental Association have developed a standard for measuring the flexural strength of dental ceramics.17 Two methodologies are described. In the 3-point bend method, a rectangular specimen is used and in the biaxial flexural strength method, a circular specimen in used. Both tests are acceptable, however, ceramics tend to produce higher values when tested with the biaxial method over the 3-point bend method due to the edge effect. The edge effect is related to the presence of chips or scratches from specimen preparation that may be present along the edge of 3-point bend specimen that are located directly under the applied load. Therefore, when the clinician compares flexural strength values of different materials, it is important that all materials were tested under the same testing conditions using the same methodology.

The ISO standard also mentions thresholds for flexural strength required for certain clinical applications. For example, materials used for a single unit crown need to be 300 MPa, a 3-unit bridge (no molars) need to be 300MPa, and a 3-unit bridge (with molars) need to be 500 MPa. These thresholds are minimum requirements. Additionally, these requirements do not take into consideration the material thickness required. Lower strength materials will require additional restoration thickness both inter-occlusal and at bridge connectors. For example, lithium disilicate restorations require bridge connectors to be 4mm x 4mm whereas zirconia bridge connectors may be 3mm x 3mm. Therefore, each clinician will have to make a clinical judgement about which material is suitable for each clinical situation. In clinical situations, in which strength is critical (such as bridges involving posterior teeth and crowns with limited interocclusal space) the increased strength of zirconia is a clear advantage.[18]

Another important property to measure for ceramic materials is their fracture toughness. Fracture toughness is the ability of a material to resist crack propagation. This test is much more difficult to perform because it requires a small, standardized crack to be placed in the test specimen prior to breaking it. Therefore, fracture toughness is less commonly reported. The fracture toughness of 3Y zirconia is about 5 MPa $m^{0.5}$, 4Y zirconia is about 4 MPa $m^{0.5}$ and lithium disilicate is 3 MPa $m^{0.5}$.[13]

What are differences between brands of zirconia

CAD/CAM zirconia blocks are composed of powders condensed into a block. Many dental manufacturers will purchase zirconia powders from a commercial distributor, such as Tosoh. Tosoh provides different powders that produce either 3Y, 4Y or 5Y zirconia. These powders can then be modified with additives such as colorants. A unique characteristic of KATANA STML Zirconia block is that its manufacturer produces powders exclusively for fabrication of their zirconia. The formulation is most similar to a 4Y zirconia.[11] One of the innovations that allows fabrication of in-house CAD/CAM zirconia restorations is the advent of speed sintering in an induction furnace. Attempts to speed sinter Tosoh zirconia in an induction furnace led to porosity in the material. The porosity caused a decreased strength and translucency. Although the mechanism by which this occurs is trade information, speed sintering of KATANA STML Zirconia does not affect its strength or translucency.[19]

How to adhesive bond zirconia restorations

Although the steps for adhesively bonding zirconia, glass ceramic or resin composite restorations are all different, the basic concepts for bonding any type of indirect restoration are the same. Generally, the intaglio surface must be roughened, then the surface must be cleaned of any contaminants introduced during try-in, and finally, the surface must be prepared with a primer to chemically link the restoration surface with a resin cement. This sequence of steps assumes that the dental laboratory roughened the intaglio surface (by etching or sandblasting) and the clinician will therefore try-in the restoration after roughening. The process may be slightly altered by the clinician performing in-office milling, because the restoration may be tried-in directly after milling. Therefore the same steps used to roughen the surface of the restoration may also function to clean any salivary contamination. For reference, the process used to bond to glass ceramics involves etching with hydrofluoric acid and then applying a silane-based primer; and bonding to resin composites is accomplished by sandblasting the surface and then applying a coat of silane and then adhesive.[20,21]

The first step of bonding to zirconia involves roughening the surface of the restoration with 50 micron alumina particles at a pressure of 1-2bar (15-30psi) for 10 seconds at a distance of 10mm. This process will roughen the surface and likely increase its surface energy. As mentioned previously, sandblasting zirconia (3Y or 4Y) does not decrease its strength as potential cracks are healed through transformation toughening.[22]

If the clinician chooses to try-in the zirconia crown after surface roughening, the intaglio surface must be cleaned of contaminants. Phosphoric acid can not be used to clean contaminants from zirconia as its use will significantly decrease the bond to zirconia. The use of cleaning solutions (such as KATANA Cleaner) have been shown to be the most effective method of removing salivary contamination from zirconia.[23]

The final step of bonding to zirconia is application of a 10-methacryloyloxy-decyldihydrogen-phosphate (MDP) primer. This molecule chemically links zirconia and resin cement. This step may be accomplished by the separate application of a 10-MDP containing primer (such as Clearfil Ceramic primer).24 Alternatively, a resin cement which contains 10-MDP, such as Panavia SA Universal, may be used without a primer.25

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