Physical Properties and Clinical Characteristics of Ceramic Brackets: A Comprehensive Review

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The popularity and clinical uses of ceramic bracket is increasing in the contemporary orthodontics. This article provides the clinician an up-to-date knowledge on the physical properties and clinical characteristics of ceramic brackets. It critically discusses the various aspects of ceramic brackets with regards to the composition, types, base characteristic, physical properties, enamel and bracket fracture, frictional resistance, bond strength, debonding methods, bracket recycling and potential clinical problems and their managements.

Introduction

An expectation of beautiful smiles at the end of orthodontic treatment is a primary concern to each patient, but is also equally concerned with appearance while undergoing treatment. Many attempts have been made by manufacturers to meet this demand. This includes by making metal brackets smaller, developing lingual or “invisible” brackets, making plastic brackets and at last introducing translucent ceramic brackets.

During the early 1970s, plastic brackets were marketed as the esthetic alternative to metal brackets. These polycarbonate brackets quickly lost favor because of discoloration and slot distortion caused by water absorption1-5. This led manufacturers to modify the plastic brackets by reinforcing the slots with metal and ceramic fillers3. Despite these alterations, the clinical problems like distortion and discoloration persisted.

In the mid 1980s, the first brackets made of monocrystalline sapphire and polycrystalline ceramic materials came into the field of orthodontics6,8. They were introduced as an esthetic appliance which, unlike plastic brackets, could withstand most orthodontic forces and resist staining. However, inability to form chemical bonds with resin adhesives, low fracture toughness and increased frictional resistance between metal arch wires and ceramic brackets were remained as major disadvantages with ceramic brackets7,9,10. Recently, a new ceramic bracket design having metal-lined arch wire slot was introduced to the market in an attempt to minimize some of the problems that were encountered by the clinician. The advantage of having a stainless steel slot was to minimize the increased friction that occurred as a result of the arch wires contacting ceramics. The metal slot also helped strengthen the bracket in order to withstand routine orthodontic torque forces.

Several ceramic brackets are available at present and their popularity and clinical uses are increasing in the contemporary orthodontics.
orthodontics. The purpose of this article is to discuss and present the various aspects of ceramic brackets used in contemporary orthodontics.

Composition and Types of Ceramic Brackets

Ceramics are a broad class of materials consisting of metal oxide elements and non-metal elements that include precious stones, glasses, clays and mixtures of ceramic compounds. In essence, a ceramic is neither metallic nor polymeric. Modern ceramic engineering has developed new ceramic materials, with numerous new applications, by taking advantage of the properties found in different atomic structures. Alumina ($A_1_2O_3$) is a typical member of modern ceramics, formed when aluminum is added to steel to remove oxygen dissolved in the steel. Alumina may be used as a single-crystal material or as a polycrystalline material. Both monocrystalline and polycrystalline alumina are used to manufacture orthodontic ceramic brackets.

All currently available ceramic brackets are mainly composed of aluminum oxide. However, because of their distinct differences during fabrication, there are two types of ceramic brackets: polycrystalline ceramic brackets and monocrystalline ceramic brackets. The manufacturing process plays a very important role in the clinical performance of the ceramic brackets. The production of polycrystalline brackets is less complicated, and thus these brackets are more readily available at present. The most apparent difference between polycrystalline and single crystal brackets is in their optical clarity. Single crystal brackets are noticeably clearer than polycrystalline brackets and hence are translucent. Fortunately, both single crystal and polycrystalline brackets resist staining and discoloration.

Ceramic brackets are available in a variety of structures including true Siamese, semi-Siamese, solid, Lewis/Lang and Begg designs etc. Many brackets are made by specialized ceramic manufacturers and are sold under proprietary names by manufacturers or distributors of orthodontic products. Currently available ceramic brackets and their characteristics are summarized in table-1. Single-crystal brackets have noticeably more optical clarity than polycrystalline brackets but whether the difference is significant or not is a judgment to be made by each clinician and patient.

Base Characteristic of Ceramic Brackets

Currently, there are two types of ceramic bracket bases available. One type of bracket base is formed with undercuts or grooves that provide a mechanical interlock to the adhesive. The mechanical retention of such brackets is less as compared to other bracket base that are having both micromechanical retention and chemical adhesion. The other type of bracket base has a smooth surface and relies on a chemical coating to enhance bond strength. A silane coupling agent is used as a chemical mediator between the adhesive resin and the bracket base. It has been claimed that chemical adhesion provided higher bond strength when compared with mechanical retention.

Recently, another two developments in ceramic bracket base technology have come that use polycrystalline alumina with a rough base comprised of either randomly oriented sharp crystals or spherical glass particles. These brackets provide only micromechanical interlocking with the orthodontic adhesive. In an attempt to overcome the potential damage of enamel during debonding, a ceramic bracket with a thin polycarbonate laminate coating on the base has been manufactured (CeramaFlex, TP Orthodontics). The bond to the enamel therefore is not through an adhesive to the ceramic base but to the thin polycarbonate laminate. It has been suggested that these brackets are as easy to remove as metallic brackets.

Physical Properties of Ceramic Brackets

Ceramics are famous for their hardness and for their resistance to degradation at high temperature and to chemical degradation.
Table 1: Currently available ceramic brackets, their made, composition, slot dimension, prescription and other characteristics.

<table>
<thead>
<tr>
<th>Bracket</th>
<th>Made</th>
<th>Composition</th>
<th>Prescription &amp; Slot Dimension</th>
<th>Other Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allure</td>
<td>GAC International</td>
<td>Polycrystalline</td>
<td>Standard Edgewise / .018&quot; &amp; .022&quot;</td>
<td>Translucent brackets, Smooth profile, Diamond cut reheated slot, High under tie wing radii, Easy to ligated, Dimpled base, Universal omni hooks, Double hooks on canines and upper premolars, Have different colour height gauge, Colour coded ID on the distogingival tie wings, No mandibular bicuspid brackets, Both chemical and mechanical retention, Debonding by squeezing at the bracket-tooth interface by debonding plier.</td>
</tr>
<tr>
<td>Aspire Gold</td>
<td>Forestadent Polycrystalline with gold alloy slot</td>
<td>Roth / .018&quot; &amp; .022&quot;</td>
<td>Contoured dovetail base, Transparent brackets, Resistance to stain, Hooks on canine and premolars, Mechanical retention.</td>
<td></td>
</tr>
<tr>
<td>Acclaim</td>
<td>ClassOne Orthodontics</td>
<td>Polycrystalline</td>
<td>Standard Edgewise / .018&quot; &amp; .022&quot; Roth / .018&quot; &amp; .022&quot; Bio-Progressive / .018&quot; &amp; .022&quot; Ricketts / .018&quot;</td>
<td>Rounded slot base, Hooks on canine and premolars, Both chemical and mechanical retention, Debracketing by ligature cutter.</td>
</tr>
<tr>
<td>Clarity</td>
<td>3M Unitek Polycrystalline with metal slot</td>
<td>Standard Edgewise/.018&quot; &amp; .022&quot; MBT / .018&quot; &amp; .022&quot; Roth / .018&quot; &amp; .022&quot; High torque / .018&quot; &amp; .022&quot;</td>
<td>Mechanical lock base, Translucent twin brackets, APC II, Bidirectional canine and premolar hooks, Torque in the base, Metal lined slot, Tie wings for easy ligation like metal brackets, Rounded contour and dome shaped profile for patient comfort, Have prominent recessed ID dot, Twin design, Base flange for easier placement and adhesive flash clean-up, Stress concentration allows for metal like debonding, Debracketing by squeezing the mesial and distal wings of the metal arch wire slot with How or Weingart plier.</td>
<td></td>
</tr>
<tr>
<td>Cerama Flex®</td>
<td>TP Orthodontics</td>
<td>Polycrystalline</td>
<td>Roth / .018&quot; &amp; .022&quot; Tip-Edge / .022&quot; 256-Begg bracket</td>
<td>Only ceramic bracket with flexible and safety base, Safest and most advanced ceramic bracket available, Patented plastic pad, Made from injection molded technique, Stronger and smoother, Translucent, Resistance to discoloration, Dovetail notch in the wings, Unique oval recess in the slot, Base is compound and contoured, Hook on the cuspid, Torque in base, Vertical slot in the Roth system, Colour coded ID system, Debonding by squeezing the plastic pad with ligature cutter.</td>
</tr>
<tr>
<td>Contour</td>
<td>ClassOne Orthodontics</td>
<td>Polycrystalline</td>
<td>Roth / .018&quot; &amp; .022&quot; Lewis and Lang / .018&quot;</td>
<td>Mechanical retention, Made from injection molded technique, Rounded arch wire slot, Low profile in the mandibular anterior, Hooks on canines and premolars in Roth system, Debracketing by ligature cutters or by band slitters.</td>
</tr>
<tr>
<td>Desire</td>
<td>Ortho Care Limited</td>
<td>Polycrystalline</td>
<td>Roth / .022&quot;</td>
<td>Mechanical lock base, Translucent compact brackets, Hooks on canines and premolars, Torque in the bracket base.</td>
</tr>
<tr>
<td>DCA</td>
<td>DCA Polycrystalline</td>
<td>Standard Edgewise / .022&quot; Roth / .022&quot;</td>
<td>Twin configuration, Impervious to stains and discoloration, Mechanical retention, No lower cuspid brackets, Hooks on canines and upper premolars.</td>
<td></td>
</tr>
<tr>
<td>Delta Force®</td>
<td>Ortho Organizers</td>
<td>Delta Force / .022&quot; Supertorque / .022&quot;</td>
<td>Pleasing esthetics, Variable ligation, Easy bracket placement, Hooks as standard 5 x 5.</td>
<td></td>
</tr>
<tr>
<td>Brand</td>
<td>Manufacturer</td>
<td>Material Type</td>
<td>Arch Wire Size</td>
<td>Features</td>
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<tr>
<td><strong>Eclipse</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>Masel Polycrystalline</td>
<td>Roth / .018” &amp; .022”</td>
<td>Mechanical retention, Translucent and stain resistance brackets, Twin brackets, Low profile design, Beveled lower incisors brackets, Reinforced tie wings, Hooks on canines and premolars, Debracketing with ceramic debonding pliers as recommended by the manufacture.</td>
<td></td>
</tr>
<tr>
<td><strong>Encore</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>Ortho Technology Polycrystalline with silver alloy slot</td>
<td>Standard Edgewise / .018” &amp; .022” Roth / .018” &amp; .022”</td>
<td>Translucent brackets, Generous contoured tie wings, Dovetail base for mechanical retention, Colour coded ID system, Hooks on canines and premolars.</td>
<td></td>
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<tr>
<td><strong>Fascination</strong>&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Dentauran Polycrystalline</td>
<td>Roth / .018” &amp; .022” Standard Edgewise / .018” &amp; .022”</td>
<td>Manufactured by two step sintered process, Optimum translucency, Excellent colour stability, Twin design, Smooth surface, Rounded contours, Silane coated base, Hooks on canines, Innovative button structure base, Easy to debond, Strength and functions are comparable to metal brackets, Positioning guide.</td>
<td></td>
</tr>
<tr>
<td><strong>Illusion Plus</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>Ortho Organizer Polycrystalline with or without silver alloy slot</td>
<td>Roth / .018” &amp; .022” Bio-Progressive / .018” &amp; .022”</td>
<td>Dovetail base, Mechanical retention, Translucent brackets, Compound and contoured design, Resistance to staining, Grooved base and porous surface, Colour coded ID system, Torque in the base, Hooks on canines and premolars.</td>
<td></td>
</tr>
<tr>
<td><strong>Integra</strong></td>
<td>Ortho-Byte Polycrystalline</td>
<td>Standard Edgewise / .018” &amp; .022” Roth / .018” &amp; .022”</td>
<td>Transparent, Stain resistance, Mechanical retention, Low profile design, Radiopaque, Hooks on canines and premolars.</td>
<td></td>
</tr>
<tr>
<td><strong>Inspire Ice</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>Ormco Monocrystalline Sapphire</td>
<td>Roth / .018” &amp; .022”</td>
<td>Translucent true twin brackets, Made by Boron carbide tumbling process and ultra smooth heat polished surface, Mechanical ball base design for mechanical retention, Tooth specific pad contour, Face-paint identification system.</td>
<td></td>
</tr>
<tr>
<td><strong>Intrigue</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>Lancer Orthodontics Ortho Care Limited Polycrystalline</td>
<td>Standard Edgewise / .018” &amp; .022” Roth / .018” &amp; .022”</td>
<td>Translucent, Grooves in the base, Mechanical retention, Torque in the base, Colour coded site tabs, Hooks on canines and premolars.</td>
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<tr>
<td><strong>InVu</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>TP Orthodontics Polycrystalline with polymer crystal mesh base</td>
<td>Standard Edgewise / .018” &amp; .022” Roth / .018” &amp; .022” MBT / .018” &amp; .022”</td>
<td>Injection molded, Low profile, Twin design, Smooth surface, Rounded arch wire slots, Ball end hooks in canines, Crystal mesh base protect enamel and debonds like metal, Debracketing by ligature cutters.</td>
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<tr>
<td><strong>LUXI II</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>RMO Polycrystalline with 18-karat gold insert</td>
<td>RMO version of Roth / .018”&amp;.022”</td>
<td>Translucent, Low profile, Twin design, Nickel free gold slot inserts, Dovetails for mechanical retention in the base, Torque in the base, Hooks on canines and premolars.</td>
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<tr>
<td><strong>Monarch</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>ClassOne Orthodontics Polycrystalline</td>
<td>Roth / .018” &amp; .022”</td>
<td>True twin wing brackets, Better rotational control, Hooks on canines and premolars, Debonding by ligature cutters.</td>
<td></td>
</tr>
<tr>
<td><strong>MXi</strong>&lt;sup&gt;TM&lt;/sup&gt;</td>
<td>TP Orthodontics Polycrystalline with polymer crystal mesh base</td>
<td>MXi Straight-Edge / .018” &amp; .022” MXi Advant-Edge / .018” &amp; .022” MXi Tip-Edge / .022” MXi 256-Begg</td>
<td>Injection molded, Smooth surface, Rounded slots, Countered edges, Crystal mesh base protects enamel and debonds like metal, Debonding by ligature cutters.</td>
<td></td>
</tr>
<tr>
<td>Brand</td>
<td>Manufacturer</td>
<td>Material</td>
<td>Features</td>
<td>Notes</td>
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<tr>
<td>Mystique®</td>
<td>GAC International TOC</td>
<td>Polycrystalline</td>
<td>Standard Edgewise / .018” &amp; .022” Roth Ovation / .018” &amp; .022” Micro-Progressive / .018” &amp; .022”</td>
<td>Translucent, Stain resistance, Low profile, Metal free diamond cut silica lined slot, NSB base, Torque in base, Double omni hooks on canines and premolars. No lower bicuspid brackets to prevent enamel abrasion, Debonding by Mystique 346RT or Mystique 1026.</td>
</tr>
<tr>
<td>Reflectio ns™</td>
<td>Ortho Technology The Dental Directory</td>
<td>Polycrystalline</td>
<td>Standard Edgewise / .018” &amp; .022” Roth / .018” &amp; .022” MBT / .018” &amp; .022”</td>
<td>Injection molded, Transparent, Stain resistance, Generous contoured tie wings, Dovetails for mechanical retention, Colour coded ID system, Hooks on canines and premolars.</td>
</tr>
<tr>
<td>Signature III™</td>
<td>RMO</td>
<td>Polycrystalline</td>
<td>RMO version of Roth / .018” &amp; .022” Standard Edgewise / .018” &amp; .022” Ricketts / .018” Bio-Progressive / .018”</td>
<td>Dovetails for mechanical retention, Torque-in-base, Underwing notches for easy ligation, Hooks on canines and premolars with Roth.</td>
</tr>
<tr>
<td>Starfire TMB</td>
<td>'A' Company Orthodontics</td>
<td>Monocrystalline</td>
<td>Andrews / .018” &amp; .022” Roth / .018” &amp; .022” Super-torque / .018” &amp; .022” (Upper only and canine to canine)</td>
<td>Only clear bracket on the market, Only straight wire aesthetic bracket on the market, Color axis indicators for easy identification and placement, Available with and without mesial and distal hooks, Debonding by the special pliers recommended by the manufacturer.</td>
</tr>
<tr>
<td>Transcend Series 6000</td>
<td>3M Unitek</td>
<td>Polycrystalline</td>
<td>Standard Edgewise / .018” &amp; .022” Roth / .018” &amp; .022” High Torque / .018” Ricketts</td>
<td>Microcrystalline lock base, Underwire tie-wing protector, Radiused corners and edges for patient comfort and esthetics, Underwire tie-wing protection ensure the labial tooth surface from out of contact with Alastik ligatures, Colour coded indicators, Adhesive coated (APC), Hooks on canines and premolars, Unique micro-crystalline bonding surface for reliable mechanical retention, Debracketing by Transcend series 6000 debonding instrument.</td>
</tr>
<tr>
<td>Virage™</td>
<td>American Orthodontics</td>
<td>Polycrystalline with palladium gold alloy inserts</td>
<td>Roth / .018” &amp; .022” MBT / .018” &amp; .022”</td>
<td>Dovetails grooves and mechanical lock base for mechanical retention, Stain and fracture resistance, 100% nickel free metal slots (Diffusion bonded slot), Smooth rounded contour, Colour coded ID, Hooks on canines and premolars, Debracketing by ligature cutters or bracket removers.</td>
</tr>
<tr>
<td>20/40m</td>
<td>American Orthodontics</td>
<td>Polycrystalline</td>
<td>Standard Edgewise / .018” &amp; .022” Roth / .018” &amp; .022”</td>
<td>Strongest ceramic brackets on the market, Small brackets with smooth harder surface, Translucent, Twin design, Rounded slot corners, Generous tie-wing undercut for easy ligation, Colour coded ID system (In slot itself in Standard Edgewise system), Bevel on the lower anteriors which reduces occlusal interferences and eliminate enamel wear, Streamline hooks on canines and premolars with Roth. Mechanical retention.</td>
</tr>
</tbody>
</table>
The physical properties of ceramics are a result of their atomic bonding. Ceramics are primarily bound together with ionic and covalent bonds, which are strong and directional. Ionic bonds, which are stronger than metallic bonds, form when a metal atom gives up its valence electron(s) to the outer shell of a non-metal atom, resulting in positive and negative ions which attract each other. Covalent bonds, the strongest type, occur when atoms of the same element or different elements share electrons. When stress is applied, the crystals fracture in a brittle fashion, because these bonds do not permit slip planes, which allow plastic deformation, to form. The physical properties of ceramics which are important to the orthodontics include hardness, tensile strength and fracture toughness or brittleness.

**Hardness**

A very important physical property of ceramic brackets is the extremely high hardness of aluminium oxide. This adds a significant advantage to both monocrystalline and polycrystalline ceramic brackets over stainless steel brackets. Ceramic brackets are nine times harder than stainless steel brackets and severe enamel abrasion from ceramic brackets might occur rapidly, if contacts between teeth and ceramic brackets exist.

**Tensile Strength**

The tensile strength is much higher in monocrystalline alumina than in polycrystalline alumina, that is in turn significantly more than stainless steel. This is the reason that the only true Siamese brackets made from ceramic material have been produced from monocrystalline alumina. Tensile strength characteristics of ceramics depend on the condition of the surface of the ceramic. A shallow scratch on the surface of a ceramic bracket drastically reduces the load required for fracture. The elongation for ceramic at failure is less than 1% in contrast with approximately 20% of stainless steel, thus making ceramic brackets more brittle under stress before fracturing, whereas ceramic brackets deforms less than 1% before failing.

**Fracture Toughness or Brittliness**

Ceramics used in orthodontic brackets have highly localized, directional atomic bonds. This oxidized atomic lattice does not permit shifting of bonds and redistribution of stress. When stresses reach critical levels, the interatomic bonds break and material failure occurs. This is called "brittle failure". Fracture toughness in ceramics is 20 to 40 times less than in stainless steel, making it much easier to fracture a ceramic bracket than a metallic one. Among ceramic materials, polycrystalline alumina presents higher fracture toughness than single-crystal alumina. The brittle nature of ceramic brackets has resulted in a higher incidence of bracket failure (fracture) during debonding. Ceramic compounds, unlike metals, are also susceptible to crack propagation caused by minute imperfections or material impurities. High-strength ceramics can fail relatively easily when cracks or imperfections allow for local concentrations of stresses. The fracture toughness of the enamel is lower than that of ceramic and ceramic brackets bonded to rigid, brittle enamel have little ability to absorb stress. Enamel fracture or the appearance of fracture lines during debonding is related to the high bond strength of ceramic brackets and seems to be associated with sudden impact loading.

The combination of very hard and brittle properties and high bond strength leads to reports of two significant problems. One is bracket fracture specifically during debonding and another is enamel fracture which may occur during function but mostly during debonding. Ceramics are radiolucent and if swallowed or inhaled would not be visible on the radiograph.

**Why Enamel and Bracket Get Fracture?**

The occurrence of the enamel fractures is due to the high bond strength of ceramic brackets. The mean bond strength for the
different bracket, adhesive and enamel conditioner combinations ranged from a minimum of 3.9MPa to maximum of 18.6MPa. Minimum bond strength of 5.9MPa to 7.8MPa was found to be adequate for most clinical orthodontic needs. However, most of the adhesives available on the market have bond strength between 5.9MPa to 11.3MPa and few studies reported maximum of 29.4MPa. The shear bond strength of ceramic brackets was found to be more than stainless steel brackets. The mean linear tensile strength of enamel is 14.5MPa. Thus, when the force required to remove the bracket from the enamel exceeds the mean linear tensile strength of the enamel or the bracket itself, fracture of the enamel surface or the bracket takes place. Retief reported that enamel fracture can occur with bond strengths as low as 13.5MPa which was comparable to the linear tensile strength of the enamel. Therefore, a debonding technique that reduces the required forces for debracketing reduces the risk of enamel fracture.

**Frictional Resistance**

It was found that under all conditions tested, stainless steel brackets had less frictional resistance than ceramic brackets; and this is most likely a result of their lower surface roughness. Polycrystalline brackets have a higher co-efficient of friction than monocrystalline ceramic and stainless steel brackets. This is due to their rougher and more porous surface. Keith et al. however did not find any significant advantage of monocrystalline brackets over polycrystalline ceramic brackets with regards to their frictional characteristics. The co-efficient of friction of monocrystalline and stainless steel brackets is however comparable. Ceramic brackets manufactured by milling or machining with diamond tools produced significantly greater rough surface. Omana, Moore and Bagby reported that ceramic brackets manufactured by injection-molding technique had less friction than other ceramic brackets. They also found that wider brackets had less friction than narrower brackets of the same material.

Comparison of frictional forces produced in ceramic and stainless steel brackets, when different wires were used, suggested that for most sizes, the wires in ceramic brackets produced significant greater friction. Also, beta-titanium and nickel-titanium wires were associated with higher frictional forces than stainless steel or cobalt-chromium wires. To reduce frictional resistance, development of ceramic brackets with smoother slot surfaces and consisting of metallic (stainless steel and gold), silica lining or ceramic/plastic slot surfaces was considered and presently accomplished. Another recent modification to further reduce friction is the introduction of bumps along the floor of the bracket slot. Unfortunately, the bumps did not appear to reduce classical friction as ceramic brackets with a single bump to the slot floor produce similar rates of binding to the conventional design.

**Bonding Ceramic Brackets**

Mechanisms for bonding ceramic brackets include mechanical retention, chemical bonding or a combination of both. Mechanical retention is achieved through indentations and/or undercuts in the bracket base. Laboratory testing of mechanical retention indicates that adhesive-to-bracket bond strengths are less than those of equivalent-size foil/mesh metal brackets. Ceramic bracket bases have considerably fewer mechanical undercuts than are found in mesh base designs, and therefore the ceramic brackets might be expected to have greater bond failure rates. Debonding is much easier with a mechanical interlock because bond strengths are apparently marginal. Chemical bonding is a more recent development in which glass is added to the aluminum oxide base and treated with a silane coupling agent. The silane bonds with the glass and has a free end of its molecules that reacts with any of the acrylic bonding materials. It produces exceptional bond strengths, but these can possibly exceed the brittle fracture resistance of the thinner areas of a ceramic bracket. The stresses of debonding can also be shifted from the bracket-adhesive interface to the adhesive-enamel interface. A rigid, brittle ceramic
bracket bonded to rigid, brittle enamel has little ability to absorb stresses. If the bracket-to-adhesive bond is too strong, then failure can only occur within the ceramic, within the adhesive, or within the enamel. A sudden impact loading is more likely to cause failure in the more brittle ceramic and enamel than in the polymeric bonding material.

**Bond Strength**

The different bond strength between mechanical and chemical bonding is due to the way stress concentration is distributed over the bonding surfaces. Ceramic brackets that offer a mechanical bond with the adhesive have retentive grooves in which edge angles are 90 degrees. There are also crosscuts to prevent the brackets from sliding along the undercut grooves that have sharp edge angles, thus leading to high localized stress concentrations around the sharp edges and resulting in brittle failure of the adhesive. On application of shear debonding force, part of the adhesive remained on the tooth and part on the grooved bracket. On the other hand, the shiny surfaces of ceramic brackets bonded chemically allow a much greater distribution of stress over the whole adhesive interface without the presence of any localized stress areas. Consequently, significantly greater shear bond was needed to cause debonding and pure adhesive failure.

Bond strength can be affected not only by the bracket base design, but also by various other factors including type of bonding resin, etching time, condition, and preparation of teeth involved. Many studies concluded that the shear bond strength of polycrystalline ceramic brackets was significantly greater than that of stainless steel brackets. Monocrystalline brackets however had higher shear bond strength than a polycrystalline structure.

**Debonding Ceramic Brackets**

As the properties of ceramic brackets differ significantly from those of the metallic brackets, techniques for removing bonded metallic orthodontic attachments are not as effective as with ceramic brackets and thus special debracketing techniques are recommended.

The first technique used for debonding ceramic brackets was mechanical. Manufacturers have produced special instruments or pliers for debonding their own ceramic brackets, although the A-Company Starfire debonding pliers may be used to remove any bracket. The pliers cause either deformation of the bracket, thus breaking the bond at the bracket-adhesive interface or by stressing the adhesive to its ultimate strength causing cohesive failure within the composite resin. Sometimes failure may occur at the adhesive-enamel interface. The force required for mechanical bond failure is very high and thus leads to enamel and bracket fracture. Swartz recommended that ceramic brackets should be debonded with a sharp-edged instrument (ligature cutter) placed at the enamel-adhesive interface, and a "slow gradual squeezing" force should be applied until bracket failure occurs.

Raising the temperature of the bracket-adhesive interface to 52°C had been shown to reduce the mechanical force required for debonding by approximately half. Handi-Dri tooth dryer marketed by Lancer orthodontics and hot tips of plier were used to heat the bracket-adhesive interface. Carter recommended hot-water bath to facilitate debracketing of ceramic brackets. Raising the temperature of bracket-adhesive interface helped to peel away the bracket from the adhesive.

An electrothermal debonding technique has been suggested as an alternative method to thermal heating. It involves heating the bracket with a rechargeable heating gun while applying a tensile force to the bracket. The electrothermal technique was found to be quick, effective and devoid of either bracket or enamel fracture. One concern with this method is related to the potential for pulp damage, because a significant rise in pulp temperature may result in pulp necrosis. However, subsequent investigations found that the heating temperature during electrothermal
debonding was too low and the heating time was too short for pulp damage, unless the adhesive material used required many heating cycles before separation and air cooling was not used simultaneously.

It has been suggested that a chemical agent can contribute to easier mechanical debonding. Post-debonding agents (GAC International Inc.) and P-de-A (Oradent Ltd.) are derivative of peppermint oil should be applied around the bracket base before mechanical debonding. According to this method, ceramic bracket removal was facilitated and bond failure took place at the adhesive-enamel interface, without damaging the tooth surface. It neither produces any significant effect on the surface micro-hardness of orthodontic resins nor softens the resin matrix but allowed easier debonding of orthodontic appliances. Laboratory studies had shown that a 60-second application of peppermint oil facilitated ceramic bracket removal and promoted failure at the adhesive-enamel interface, without damaging the tooth surface.

An ultrasonic debonding technique has been used to create a purchase point within the adhesive between the bracket base and the enamel surface. In this technique, the brackets are debonded with KJS ultrasonic tips and the Cavitron 2002 ultrasonic unit (Dentsply International). The advantages of the ultrasonic debonding approach include a decreased chance of enamel damage, a decreased likelihood of bracket failure and the ability for the removal of the residual adhesive with the same instrument after debonding. Many authors found bond failures at the enamel-adhesive interface with this approach. However, there are a number of disadvantages associated with the ultrasonic technique, including a significantly increased debonding time, excessive wear of the expensive ultrasonic tips, the need to apply moderate force levels, which could create some discomfort to sensitive teeth, the potential for soft tissue injury by a careless operator, and the need for a water spray to reduce the heat build-up and to minimize any possibility of pulpal damage.

Since the ultrasonic method is effective but time consuming, its use might be indicated when a ceramic bracket fractures while the conventional method is being used and part of it remains attached to the tooth.

The use of lasers (Nd:YAG and CO₂) for debonding ceramic brackets has been investigated. The proposed laser-aided debonding technique was found to significantly reduce the residual debonding force, the risk of enamel damage and the incidence of bracket fracture as compared with the conventional methods. This technique has the potential to be less traumatic and painful for the patients and less risky for enamel damage. It was found to favor bond failure at the bracket-adhesive interface with no bracket or enamel damage. After CO₂ laser illumination for 2 seconds the average torque force necessary to break the adhesive between the polycrystalline ceramic brackets and the tooth was lowered by a factor of 25. Similarly the average torque force needed to debond monocrystalline brackets was lowered by a factor of 5.2. Stroble et al. concluded that the debonding mechanism was thermal softening of the resin adhesive by the laser induced heat which transmitted through the bracket to the resin. Actually laser-initiated resin degradation can occur as the result of either thermal softening or thermal ablation or photoablation.

**Recycling of Ceramic Brackets**

Ceramic brackets are much more brittle than conventional metallic brackets and therefore are more likely to fracture than to distort on debonding. The intact debonded brackets do not lose their precisely machined angulation, torque, and base contour. Recycling of debonded or dislodged brackets provides a substantial savings in the expense of maintaining a bracket inventory. A method of recycling ceramic brackets was suggested by Lew and Djeng. In recycling procedure, first any composite resin remaining on the bracket base should be removed by holding the bracket with a pair of tweezers and heating it in a Mini-Torch until it turns cherry red. After it the bracket should be allowed to...
cool until it reaches room temperature and the residual composite which appear as chalky white and flaky should be removed by gently tapping the bracket on a table top or by lightly scraping the base with a wax knife. Than the base should be dried and cleaned with compressed air to remove any possible residue followed by rinsing it in 100 percent isopropyl alcohol or-pure acetone. To restore the silane layer on chemically treated bases or, if desired, to improve the retention of mechanically interlocking bases, a thin layer of a porcelain primer should be applied with the help of a brush. Before applying the porcelain primer, phosphoric acid etchant with a cotton pellet should be applied on the base for 60 to 90 seconds. The acid should not be rinse off, because it is used to hydrolyze the hydrogen atoms and hydroxyl groups in the silica surface. After this porcelain primer should be applied over the acid and left it on the surface for one minute before rinsing and drying thoroughly. After 10 minutes of air drying, the primed brackets should be bonded to the etched enamel surfaces with either a chemically or light-cured composite resin. Comparison of debonded ceramic bracket bases with those of recycled brackets after heating and application of the silane coupling agent suggested that the "recycling" method was effective in providing a clean surface. Bond strength of recycled brackets was appeared to be clinically adequate, although it was significantly lower than that of new brackets. This weaker bond strength after "recycling" of ceramic brackets however minimized the likelihood of unwanted enamel removal during debonding.

Optimizing Ceramic Bracket Performance
Ceramic brackets have the potential to meet the practitioner’s demand for excellent performance, as well as the patient’s demand for superior esthetics. Of course, like any new material, ceramics may require technique modifications.

One of the major causes of ceramic bracket breakage during treatment is due to torquing force. It is advisable to use proper wire sequence during leveling and alignment phase instead of using thick stainless steel wire prematurely. Use of sequential nickel titanium rectangular archwires helps easier insertion of stainless steel rectangular wires later, with less chance of bracket breakage. Treatment with sliding mechanics is expected to proceed very slowly with any type of arch wire-ceramic bracket combination. Traditionally with metal brackets, closing loops are used for closing extraction spaces and power chain for smaller spaces. With ceramic brackets, it is advisable to use closing loops even for small spaces. Enamel abrasion or wear can appear suddenly where teeth come in contact with ceramic brackets. Any patient considering ceramic appliances should be informed of the potential for enamel abrasion. Additionally, a patient with a deep bite or a history or evidence of bruxism should start treatment with a reverse-curve nickel titanium wire, which will immediately begin to open the bite. The mandibular brackets should also be positioned more gingivally than usual. If wear is noted within the first month or two, a bite plane should be considered. Alastigard ligatures (elastomeric ligatures with pads) can be used where brackets come in contact with teeth. In some situation it is advantageous to bond only the upper arch until some leveling and aligning have occurred. Brittleness of the tie wings is most problematic in ceramic brackets. It is advisable to avoid heavy forces. During torquing nickel titanium wire should be used because of their springiness and rounded edges. Ligature wires should be Teflon-coated and never larger than .010". If possible elastomeric ligatures should be used. Hooks should be bent, soldered, or clamped to the wires instead of tied to the brackets.

Potential Clinical problems and Their Management
Various complications during the use of ceramic brackets in clinical practice are common. The major problems include enamel fracture during debonding, bracket fracture, increased friction, patient discomfort during debonding and attrition of teeth occluding against the bracket.
measures to overcome these problems are discussed.

**Problem 1:** Enamel fracture during debonding.

Enamel fracture during debonding is related to the high bond strength of ceramic brackets and sudden impact loading\(^{37,38}\). Enamel fracture during debonding can be prevented by avoiding sudden impact loading or stress concentration within the enamel by using proper debonding techniques\(^{75}\), avoiding bonding of ceramic brackets on structurally damaged teeth i.e. teeth having crack lines, heavy caries, large restorations, hypoplasia, hypocalcification and nonvital tooth\(^{55}\) and by reducing the bond strength of ceramic brackets by adding mechanical retention\(^{19,37}\), by reducing chemical retention\(^{76}\), by adding a metal mesh at the base of the bracket, by reducing the base area of the brackets, by using weaker resins\(^{76,77}\), by adding extra plasticizer to the resin\(^{78}\), by modifying the thickness of adhesive used\(^{19}\), by modifying the etching time and/or concentration of etching acid (H\(_3\)PO\(_4\))\(^{4,80,81}\) and by debonding with ultrasonic, electrothermal and laser devices\(^{6,62,82,83}\).

**Problem 2:** Removal of broken ceramic brackets by grinding.

When a proper debonding technique fails, and/or risks subjecting the tooth to increased forces and fracture, grinding the ceramic bracket becomes the option of choice. Grinding should be carried out with high-speed diamond burs or low-speed green stones. The procedure is time-consuming and the heat which generated by grinding might affect the dental pulp and subsequently, the vitality of the tooth\(^{84}\). Such problem can be managed by selecting the teeth to be bonded with ceramic brackets. The clinician must avoid bracket contact with the opposing teeth. In deep anterior overbite cases, bonding the mandibular teeth with ceramic brackets should be avoided. Similarly in cases where the maxillary canine is retracted past the mandibular tooth, bonding the mandibular canine should be avoided.

**Problem 3:** Attrition of teeth occluding against ceramic brackets.

It represented the highest percentage of injury from ceramic brackets\(^{85}\). It is due to the fact that ceramic brackets are harder than enamel\(^{18,29,36,87}\). Such problem can be overcome by selecting the teeth to be bonded with ceramic brackets. The clinician must avoid bracket contact with opposing teeth. In deep anterior overbite cases, bonding the mandibular teeth with ceramic brackets should be avoided. Similarly in cases where the maxillary canine is retracted past the mandibular tooth, bonding the mandibular canine should be avoided.

**Problem 4:** Increased friction with ceramic brackets.

High friction is due to the roughness of the bracket interface which slows the sliding of the archwire through the bracket\(^{10,36,50,87}\). This clinical problem can be managed by selecting the teeth to be bonded with ceramic brackets. The clinician must avoid bracket contact with opposing teeth. In deep anterior overbite cases, bonding the mandibular teeth with ceramic brackets should be avoided. Similarly in cases where the maxillary canine is retracted past the mandibular tooth, bonding the mandibular canine should be avoided.

**Problem 5:** Breakage of ceramic brackets.

This is due to the low fracture toughness of the ceramic brackets\(^{88}\). It often affects bracket wings and usually occurs accidentally when cutting ligature wires or engaging a heavy archwire in the bracket. Sometimes the slightest torque of such wire in the bracket interface leads to fracture\(^{4}\). Such problem can be avoided by avoiding direct contact of the brackets while cutting ligature wires and forceful engagement of increasingly heavy archwires used for leveling. Successive archwires should be fully engaged in the brackets. Also, it may be safer to avoid using ceramic brackets in people prone to trauma because of professional or numerous sports activities, such as football, martial arts or other contact sports.

**Problem 6:** Increased pain or discomfort while debonding ceramic brackets.

This is related to the higher bond strength and it can be managed by having patient bite with pressure on cotton roll and/or gauze during debonding.
Problem 7: Esthetic results that is not absolute.

Although ceramic brackets hold a definite advantage over plastic attachments, some polycrystalline brackets do stain. This is probably due to prolonged use of caffeine (coffee, tea, colas), certain mouthwashes or lipstick, and may also be associated with the type of bonding resins used. It is necessary to avoid excessive use of staining substances and discoloring resins. Ceramic brackets may look discolored when the brackets themselves stain (direct discoloration) or when stains on the teeth or bonding resin show through the bracket (indirect discoloration). It tends to occur with polycrystalline brackets which represent the majority of the ceramic brackets manufactured and so, are most commonly used. Using two-base resins, which tend to discolor less than no-mix one-step bonding resins, has been advocated by Swartz who also suggested the light-cured resins may offer “excellent color stability.”

Problem 8: Operational risks.

The primary operational risk for the patient is the accidental ingestion or aspiration of a bracket during bonding or debonding or of bracket particles if the bracket fractures during debonding. Because of their radiolucency, ceramic brackets may not be detected on radiographs if aspirated. Also, during debonding, fractured fragments may subject the patient to oral soft tissue damage, and the patient, clinician and assistant to eye injury. The solution for this is to use caution and protective equipment during bonding and debonding. Instructing the patient to bite on a cotton roll during debonding helps reduce the risk of dislodging brackets and/or fragments into the oral cavity and throat. The clinician and assistant should wear protective glasses and a mask. The patient should wear protective glasses as well or at least keep both eyes shut.

Conclusion

Ceramic brackets are popular as an esthetic appliance in the contemporary orthodontics. Its introduction is a much-heralded development in the orthodontic treatment of adult patients. The acceptance of ceramic brackets by the patients has been unprecedented in the practice of orthodontics and contributed significantly in the expansion and development of contemporary orthodontic therapeutic modalities.

References


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