ADVANCES IN PRODUCT DESIGN AND MANUFACTURING CREATE A SUPERIOR AESTHETIC BRACKET

In the last few years the ceramic market has easily established itself as the fastest growing segment of orthodontics. Orthodontic patients, including a growing population of adults, not only want an improved smile, but they also want to look good during treatment. Ceramic brackets offer many advantages over traditional aesthetic appliances (initially made from acrylic and later composite) because they provide higher strength, more resistance to wear and deformation, better color stability and, most important to patients, superior aesthetics.

All currently available ceramic brackets are composed of aluminum oxide; however, because of their distinctly different methods of fabrication, there are two types of ceramic brackets, namely, polycrystalline and monocrystalline.[1-5] The most apparent difference between the two is their optical clarity; monocrystalline ceramic brackets are noticeably clearer.[2,6] Because of their rough surface, polycrystalline ceramics have a higher coefficient of friction than monocrystalline ceramics and stainless steel. Manufacturers have attempted to resolve this issue by inserting a metal slot in the bracket to provide smoother sliding mechanics. Furthermore, polycrystalline ceramic brackets may require a metal slot insert to help strengthen them to withstand routine orthodontic torque forces. In contrast, monocrystalline ceramics have friction characteristics equal to metal; therefore no metal slot insert is required.

There has also been a concern expressed about the overall strength and fracture toughness of both polycrystalline and monocrystalline ceramic brackets. This article specifically addresses ceramic bracket strength, explains how product design and manufacturing processes play a large role in strength, as well as discusses a relatively new aesthetic appliance that has undergone a change in manufacturing process to be even stronger and more robust during treatment than ever before.

In September of 1999, Ormco introduced Inspire. Inspire is the only bracket on the market made of monocrystalline sapphire (a ceramic material) and is, therefore, the only completely transparent bracket on the market. Combining the strength, wear resistance and color stability inherent in ceramic material with frictional characteristics equal to metal and enhanced optical clarity (compared with polycrystalline appliances), Inspire has quickly become the fastest growing appliance in the orthodontic ceramic market.

Bracket Strength

There are two things that determine the strength of a ceramic bracket: product design and manufacturing process. (Torque slot strength and tie-wing strength are synonymous when discussing ceramic brackets, so when discussing strength, the reference will be to overall bracket strength.)

Product Design – In brackets made of a ceramic material, the design of the inner slot and tie-wings are critical to the strength of the appliance. One important design element is the *slot wall thickness* (Figure 1). A wall that is too *thin* will not adequately endure the stresses of wire torquing or tying in elastomeric and stainless steel ligatures. A wall that is too *thick* will limit the amount of under-tie-wing area and add to the overall occlusogingival height of the bracket. Inspire's slot wall thickness provides an ideal balance of tie-wing strength and under-tie-wing area.

Another important design element of ceramic brackets (that don't incorporate a metal slot insert) is the shape of

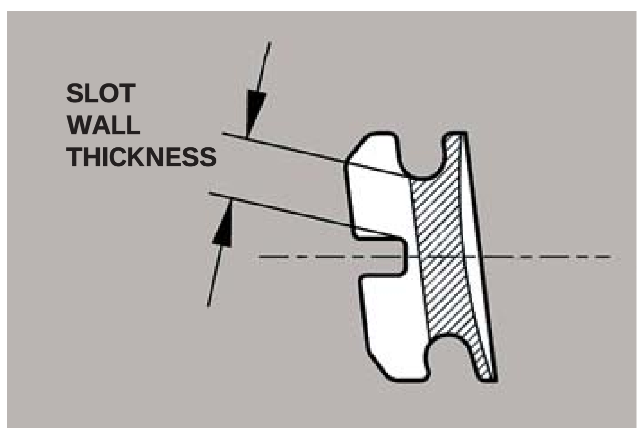

Figure 1. Slot Wall Thickness is a crucial design element of ceramic brackets. If too thin, the bracket will not adequately endure the stresses of wire torquing. If too thick, the under-tie-wing area will be limited.

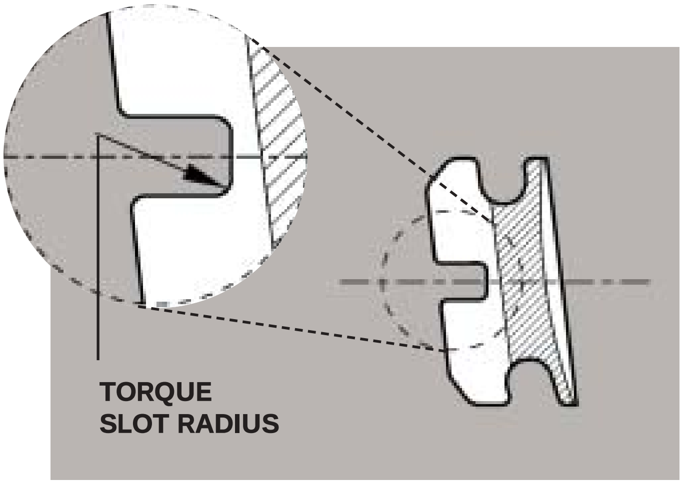

Figure 2. Inspire features a Torque Slot Radius, which is a rounding of the corners of the archwire slot. This gradual change in geometry minimizes stress points, allowing Inspire brackets to withstand considerable orthodontic force loading from wire torquing or occlusal forces.

the archwire slot. Because ceramic materials exhibit such a high hardness level and a tendency to be brittle, introducing any abrupt change in geometry (such as a sharp-cornered archwire slot) has the potential to act as a source of *point loading*. Point loading occurs when force is localized in a small region of the material and results in stress concentration at that point, causing a bracket to chip or break. To avoid such a phenomenom, Inspire features a *Torque Slot Radius*, which is a rounding of the corners of the archwire slot (Figure 2). This feature eliminates a sharp corner where the bottom of the slot meets the vertical walls. This gradual change in geometry minimizes stress concentration, allowing Inspire brackets to withstand considerable orthodontic force loading from wire torquing or occlusal forces.

Manufacturing Process – The second thing that determines strength of a ceramic bracket is its manufacturing process. Because ceramic brackets are milled from rods of material, their dimensions are created by *grinding* a specified shape out of that rod. Grinding the bracket into its shape produces minute imperfections at the surface of the material. Even a shallow scratch on the surface of a ceramic bracket will drastically reduce the load required for fracture.[7] Unlike polycrystalline materials, monocrystalline ceramics can be put through a heat-treatment procedure to heal those surface flaws before the manufacturing process is complete. This procedure, known as *heat polishing*, involves heating the material to near melting point and holding it for a specified amount of time at that temperature, which is known as the *optimum heat-polishing temperature*. This ensures that all parts are equally affected. The optimum heat-polishing temperature is the temperature required to create enough surface energy to allow movement of atoms into these flaws, filling them to obtain a strong, smooth bracket (Figures 3-4). This process naturally identifies stress points in the bracket and forms a new crystal bond at that point, thus relieving the stress and healing any surface imperfections. All parts then cool to room temperature at a defined cooling rate. The sequence of this heat-polishing process is just as important as the process itself. Upon completion of this phase, Inspire brackets have what is referred to as a *maximum residual strength* or *minimum residual stress*. Ormco's heat-polishing process takes place after the brackets have completed all other stages of manufacturing

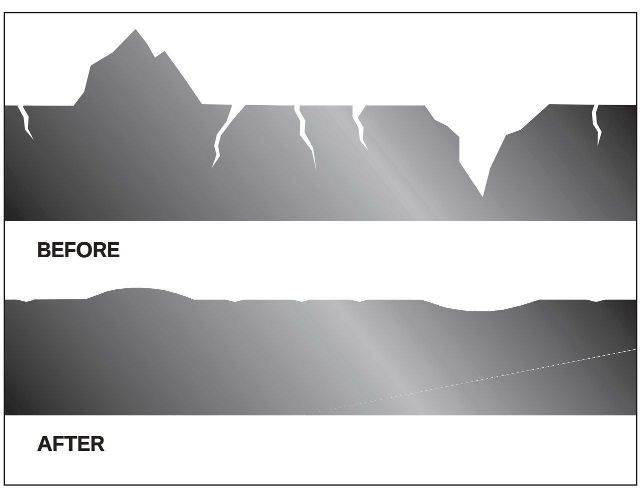

Figure 3. Inspire brackets are heat polished to fill in minute surface flaws. The illustrations show microscopic view of the bracket surface before and after heat polishing.

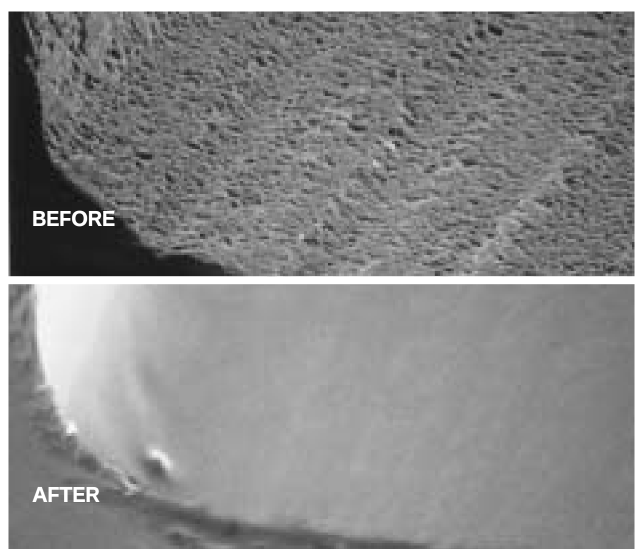

Figure 4. The electron micrographs show Inspire before and after heat polishing, which creates a smoother surface and dramatically increases the strength of the bracket.

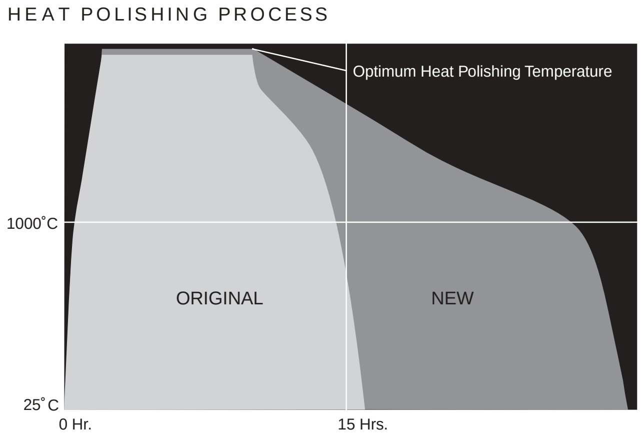

Figure 5. Increasing the Optimum Heat Polishing Temperature by 30°C and slowing the cooling rate by a factor of 5 during the heat polishing process produces an Inspire bracket that is almost twice as resistant to breakage as before.

(which includes the final tumbling process), ensuring that no additional stress points are introduced. In contrast, surface flaws on a polycrystalline ceramic bracket cannot be repaired via heat polishing due to its molecular structure; therefore, the only way to obtain an acceptable finish on these types of ceramics is to grind the material down farther, mechanically abrade the surface, or insert a stainless steel archwire slot.

A significant change has recently been made to Inspire's heat-polishing process, making the bracket more resistant to tie-wing and slot breakage specifically due to wire torquing. Through continuous research into improving Inspire's clinical performance, Ormco discovered that adjusting the heat-polishing process in two key areas produces a bracket that is almost twice as resistant to such breakage as before. Those two areas are as follows:

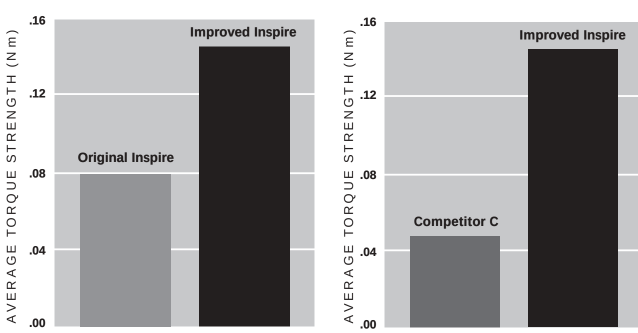

Figure 6. Left: With improvements to the heat-polishing process, Inspire brackets now have an average torque strength of .144 Nm, which are 180% as strong as the original Inspire brackets. Right: Improved Inspire brackets are 290% as strong as the leading competitive bracket.

1. increasing the optimum heat-polishing temperature by approximately 30° C; and
2. slowing the rate at which brackets cool down to room temperature by a factor of 5 (Figure 5).

The original heat-polishing process produced Inspire brackets with an average torque strength of .08 Nm (Newton meters). With these improvements, the process now produces brackets with an average torque strength of .144 Nm. Inspire's leading competitive bracket has an average torque strength of .049 Nm; thus, the recently improved Inspire brackets are 180% as strong as the original and 290% as strong as its leading competitor (Figure 6).

Testing and Validation

On average, Inspire brackets are produced in lots of 800. From those 800, 6 brackets are randomly selected for torque strength testing and process efficacy validation. Of those 6 brackets, 2 are selected from the bottom of the lot, 2 from the middle and 2 from the top to ensure that all

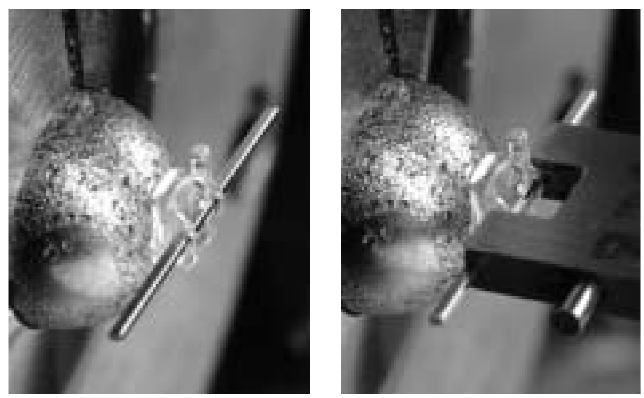

Figure 7. Inspire brackets are randomly selected for torque strength testing. Left: Brackets are then glued to stainless steel balls and ligated with straight-length stainless steel wire. Right: Torquing key is attached to the wire and the entire unit is affixed to an Instron test machine.

parts within a lot are heat polished equally, regardless of location in the oven. The selected brackets are then glued to 1/4-inch round stainless steel balls, and depending on the slot size in a particular lot, either .018 x .025 or .021 x .028 straight-length stainless steel archwires cut into 1/2-inch segments are ligated into the brackets using clear .120 elastomeric ties. Five of the balls with brackets and wire (the sixth is held in case an extra is needed) are affixed with a torquing key (Figure 7) to housings on an Instron® test machine (Figure 8). The Instron machine is designed to place a load to the end of the torquing key, which in turn torques the archwire (Figures 9-10) until one of the following occurs:

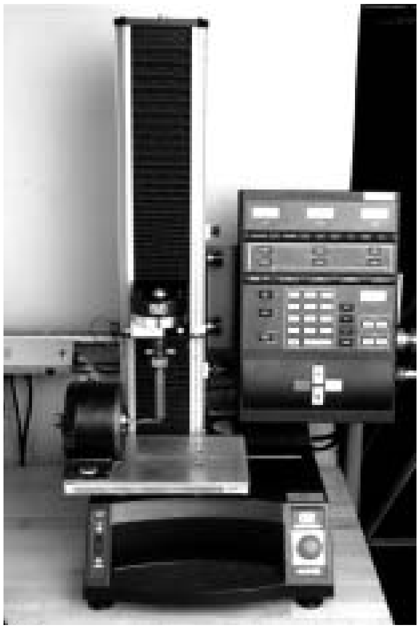

Figure 8. The Instron test machine measures torque strength of an Inspire bracket by placing a load to the end of a key that torques the wire ligated in a bracket.

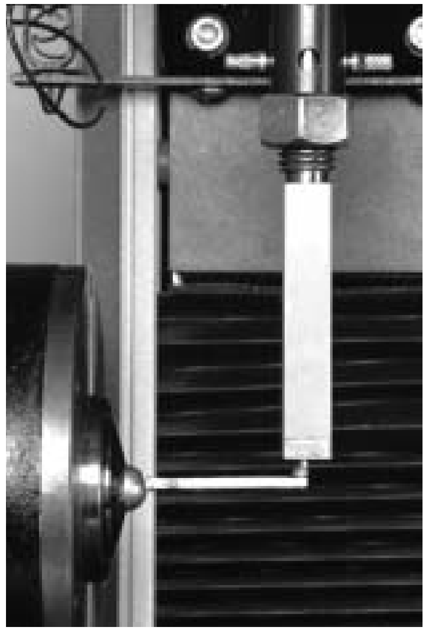

Figure 9. The initial test position of the torquing key before a load is applied.

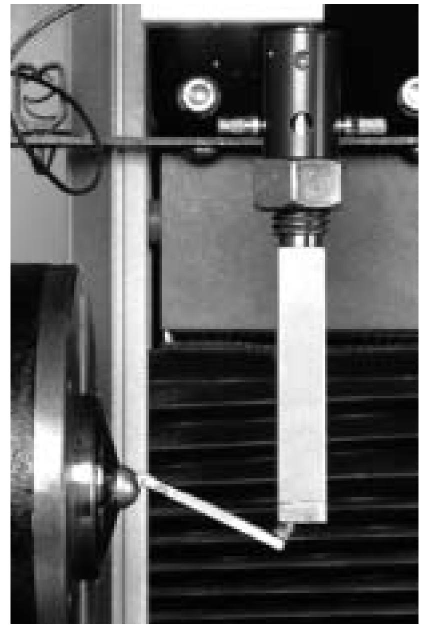

Figure 10. The final test position of the torquing key with 19.5 mm of wire displacement (14.11 Nm of torque).

1. part of the bracket fractures (e.g., tie-wing);
2. the bracket debonds (from the stainless steel ball); or
3. a maximum displacement of 20 mm is reached and nothing happens to the bracket.

The torque strength is then measured in Newton meters on all 5 brackets and the results recorded. The mean of these measurements is calculated and documented as the average bracket strength for that particular lot. This same testing method was also used to validate recent adjustments to Ormco's heat-polishing process and the results were a new average Inspire bracket strength of .144 Nm.

Conclusion

With the ceramic bracket market firmly established as the fastest growing segment of orthodontics, it is more important than ever to have an appliance that not only provides superior aesthetics but also consistently performs at a level desirable to the clinician. Ormco's Inspire bracket is manufactured from transparent, monocrystalline sapphire with design elements that ensure reliable performance throughout treatment. Ormco's recently improved proprietary heat-polishing process produces an Inspire bracket that is stronger and more dependable than both its predecessor and leading competitor.

References:

1. Birnie, D.: Ceramic brackets. Br. J. Orthod., 17:71-5, 1990.

2. Swartz, M.L.: Ceramic brackets. J. Clin. Orthod., 22:82-8, 1988.

3. Gwinnett, A.J.: A comparison of shear bond strengths of metal and ceramic brackets. Am. J. Orthod. Dentofac. Orthop., 93:346-8, 1988.

4. Phillips, H.W.: The advent of ceramics: the editor's corner. J. Clin. Orthod., 22:69-70, 1988.

5. Viazis, A.D.; DeLong, R.; Bevis, R.R.; Douglas, W.H.; & Speidel, T.M.: Enamel surface abrasion from ceramic orthodontic brackets: a special case report. Am. J. Orthod. Dentofac. Orthop., 96:514-8, 1989.

6. Viazis, A.D.; Cavanaugh, G.; & Bevis, R.R:. Bond strength of ceramic brackets under shear stress: an in-vitro report. Am. J. Orthod. Dentofac. Orthop., 98:214-21, 1990.

7. Karamouzos, A.; Athanasiou, A.E.; & Papadopoulos, M.A.: Clinical characteristics and properties of ceramic brackets: A comprehensive review. Am. J. Orthod. Dentofac. Orthop., 112;34-40, 1997.