Strength testing variables in dental ceramics

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Chapter 8

Summary and conclusions

The present series of studies investigated the mechanical behavior of dental porcelains and ceramics under various conditions. Strength demonstrates the “initial” resistance of a material against fracture. Besides the strength, fracture toughness and fatigue are important factors in the survival of porcelain and ceramic based restorations. The fracture toughness and the fatigue resistance describe the ability of a material to resist crack growth. This thesis focused on different methods to evaluate strength, fracture toughness, and fatigue with the aim to obtain clinically relevant values.

In Chapter 2, three test methods were used to compare the fracture toughness of the dental porcelain Carrara Vincent, and a soda lime glass. The soda lime glass has a homogeneous microstructure, while the traditional dental porcelain is feldspar-based and leucite-reinforced, which improved the fracture toughness. The fracture toughness was determined with the following methods; Indentation-Strength-in-Bending method (ISB), Single-Edge Notched Beam (SENB), and Chevron-Notched Beam (CNB). The results of the different fracture toughness tests were dependent on test methods and material. ISB, SENB, and CNB were not consistent with each other. Because only two materials were investigated it was hard to generalize the conclusions of this study that microstructure and chemistry of materials may influence the fracture toughness results of individual test methods. It seemed that technical reasons, like preparation and way
of testing, were also important factors. Anyhow, it showed that one should realize that fracture toughness values from different test methods might not be comparable.

In Chapter 3, the influence of the same three fracture toughness test methods was further evaluated with four commercial dental porcelain materials with different $K_{IC}$ values. For these materials the CNB and SENB test were statistically consistent. According to the results mentioned in Chapter 2, Carrara Vincent had statistically different toughness when evaluated with CNB and SENB, while in the current study, the same different values were not significantly different. Furthermore, it was shown that the ISB method was not always in agreement to CNB or SENB. Also in literature, fracture toughness methods may present different values for same materials and different ranking of varied materials, in a same manner as strength tests. For dental porcelains and ceramics, which have a broad variation in microstructure, chemistry, and fracture toughness, it is useful to systematically assess the comparability of the different test methods with standardized method.

The effect of the strength test configuration and the crosshead speed with the indentation-strength-in-bending method (ISB), which is easy and fast compared to SENB and CNB, was evaluated in Chapter 4. The fracture toughness and the 3-point, 4-point, and biaxial strength were determined for two dental porcelains. It was found that in an ISB test the 3-point, 4-point, and biaxial strength setups did not have a significant influence. However, the crosshead displacement speed was of influence for some test conditions.

In Chapter 5, the influence of the indentation load of the ISB method was evaluated. A higher load significantly increased the found toughness values. Specimens were rejected if they did not fail from the indentation, but from a flaw on the tensile surface. The tougher materials showed to have smaller indentation flaws and more rejected specimens. At small flaw sizes, rejected ISB specimens were often stronger than average. Testing the un-indented strength of identical specimens to verify that the indented strength is sufficiently lower can be a safe requirement for a valid experiment. When using ISB methods for comparing materials with different toughnesses, the indentation load applied to create predictable surface flaws should be adjusted for each material.

Chapter 2, 3, 4 and 5 were helpful to understand fracture toughness assessment and its sensitivity to the test configurations. Meanwhile, one has to keep in mind that small-crack and large-crack methods for fracture toughness measurement may lead to different resistance to crack growth. The mentioned chapters were focused on dental porcelains and ceramics, which are used in PFM restorations and as layering porcelain
in all-ceramics. The zirconia in all-ceramic restorations is used as core material instead of a metal. During the fabrication processes, like shaping, trimming, sandblasting, machining and grinding, the zirconia surface is damaged. The induced flaws may compromise the strength, toughness and fatigue resistance.

In Chapter 6, after CAD/CAM machining and/or sandblasting with 120 μm, the tested zirconia showed a significantly reduced strength compared to polished specimens. However, sandblasting with 50 μm alumina did not decrease strength of zirconia so much and was statistically close to polishing. On the contrary, it increased not only the strength of ‘as-sintered’ and machined zirconia but also their structural reliability, which may be explained by the removal of large surface damages.

In Chapter 7, the fatigue resistance of the same zirconia was investigated. It was found that sandblasting with 50 μm particles produces significantly less degradation than sandblasting with 120 μm particles. For this zirconia, sandblasting with 50 μm was recommended for long-term clinical performance. Based on the obtained fatigue resistance of these zirconia ceramics, it was shown that different fabrication processes might lead to different strength degradation. The insensitivity of the studied zirconia to sandblasting might be explained by the grain interface and phase transformation-triggering stress levels.

Strength, toughness, and fatigue resistance tests of dental porcelains and ceramics were investigated. For toughness measurements, the test setup design should be carefully considered. The method should be chosen based on the materials’ service condition. The processing of the materials and specimens should be considered, as during the fabrication process flaws are introduced, which may lead to a reduction of the strength, fracture toughness, fatigue resistance and ultimately the clinical survival rate. In conclusion, strength and toughness tests must be well designed and performed for the estimation of the clinical survival rate of dental ceramic systems.