

Fracture Behavior of Monolithic Hot-Pressed Posterior Ceramic Dental Crowns

L Porojan^{1,*}, L Rusu², A Boloş³, C Savencu¹ and S Porojan³

¹Department of Dental Prostheses Technology (Dental Technique), School of Dentistry, “V. Babeş” University of Medicine and Pharmacy, 9 Revolutiei 1989 Blv., 300041 Timișoara, Romania

²Department Mechanics and Vibrations, Faculty of Mechanical Engineering, Politehnica University, 1 Mihai Viteazu Street, 300222 Timisoara, Romania

³Department of Oral Rehabilitation (Dental Technique), School of Dentistry, “V. Babeş” University of Medicine and Pharmacy, 9 Revolutiei 1989 Blv., 300041 Timișoara, Romania

*Corresponding author: sliliana@umft.ro

Abstract. Glass ceramic restorations are wide used in dental practice due to their advantages as life-like appearance, excellent biocompatibility, chemical inertness, close abrasion resistance to enamel, but their most common mechanical complications are chipping and catastrophic fracture. The purpose of the study was to evaluate monolithic ceramic posterior crowns with anatomical design, achieved by hot-pressed glass ceramics, without filler Cergo (Degudent) and leucite reinforced Vita PM9 (Vita) by experimental analyses, in order to study their fracture behavior under compressive load. The modes of fracture will be correlated with the type of material, fracture load and displacement magnitude. For the experiments complete crown preparation were made on a first upper molar. The specimens were subjected to failure testing. Digital images of the fractured crowns fragments were used to verify the pieces in all situations. The failure occurred by cracks, splitting into two or more parts, with or without fracture of the die. The correlation of the displacement depending on the load highlights the peaks, which can be correlated with cracks produced in time. Within the limitations of this study, the tested hot-pressed monolithic ceramic crowns show similar fracture strength and fracture behavior.

1. Introduction

Ceramic crowns are developed as aesthetic restorations because of their life-like aspect, and are characterized by excellent biocompatibility, chemical inertness, close abrasion resistance to enamel, but they have different strength values and structural characteristics related to the composition, and chosen design [2-4]. Glass ceramic restorations are wide used in dental practice due to their advantages mentioned above, but their most common mechanical complications are chipping and catastrophic fracture.

Monolithic silicate ceramic is highly aesthetic and has been used over time for inlays, onlays and veneers with success. However, for bigger restorations, like crowns, more complete fractures were registered [5,6]. Silicate ceramic restorations are brittle and fragile if they are designed very thin. Therefore it is important to chose the optimal thickness and design [7,8].



Monolithic all-ceramic crowns are more and more chosen in practice, compared to the traditional bilayered restorations, because of the disadvantages, related to the complex fabrication, resulted residual stresses, and delamination of the veneers [9-10]. Zirconia and glass-ceramics are aesthetic materials of choice, due to their relatively high modulus and fracture strength [11-15]. All-ceramic crowns absorb occlusal stresses due to their stiffness, but brittleness is still a concern, because different failures of monolithic crowns are described in dental practice [16-18]. These failures could be "abrupt" or catastrophic, with a complete cracking of the crown and sometimes of the dental structure. Other types of fracture involve with chipping of veneering ceramics. There are not many studies which describe the cracks related to the material properties and crown design [19,20].

An important disadvantage of all-ceramic restorations is the manufacturing procedure, associated with a high thermal expansion coefficient and a low thermal conductivity. Therefore the susceptibility to the thermal shock is important for the further behavior. The exposure of all-ceramic restorations to rapid temperature changes during the manufacturing process (pressing, sintering, grinding, polishing) leads to thermal stresses in the material. The pressure of sandblasting, grinding and polishing during processing, and external loading in use, such as occlusal forces during mastication could provide an associated mechanical stress. The combined effect of both thermal and mechanical stress can lead to failure of all-ceramic dental restorations in time [21,22].

Most glass ceramic restorations are indicated to be glazed. Glazing can increase the fracture strength, the wear resistance, produce a smoother surface, and can prevent nucleation and crack propagation [23-25]. Experimental analyses should reproduce the clinical behavior, including the occlusal load and lead to failures similar to those observed in restorations after clinical use [26-28]. Chipping is frequently shown on functional cusps and marginal ridges. These failures are repairable or not, and depend on the location and extension. Catastrophic failure, or fracture throughout the total thickness of the restoration divides it into two or more pieces.

The purpose of the study was to evaluate monolithic ceramic posterior crowns with anatomical design achieved by hot-pressed glass ceramics, without filler Cergo (Degudent) and leucite reinforced Vita PM9 (Vita) by experimental analyses, in order to explain their fracture behavior under compressive load. The modes of fracture will be analyzed, correlated with the type of material, fracture load and displacement magnitude.

2. Materials and methods

Two restorative materials for monolithic dental crowns were selected for the study, both hot pressed glass ceramics. Experimental analyses were made on a full crown preparation made on a first upper molar from a typodont model. The axial reduction was 1.5 mm with a convergence angle of 6 degree, and the occlusal one was 1.5-2 mm. For the finish line a 1 mm deep chamfer was chosen. All sharp angles of the preparation were rounded in order to avoid stress accumulation. The preparation was replicated with a composite material Structur 3 (Voco, Cuxhaven, Germany), which has properties similar to the tooth structure. The dies were scanned using Cercon Eye and dedicated CAD (computer aided design) software Cercon Art (Degudent, Hanau, Germany) was used for the design of crowns with full anatomic design. In order to obtain identical samples for the experiments, sixteen wax-ups were milled from a Cercon base cast material. These were invested, and specific steps were covered according to the manufacturer's instructions in order to obtain heat pressed ceramic crowns using Cergo (Degudent, Hanau, Germany) (samples C1-C8) and Vita PM 9 (Vita, Bad Säckingen, Germany) (samples V1-V8) ceramics. The restorations thickness was verified by periodic measurements at several locations. The crowns were glazed and adhesive luted with Maxcem Elite (Kerr, Biberach, Germany) on the composite dies.

A digital load was applied to the occlusal surface of the crowns during adhesive setting and the the samples were maintained 24 hours before loading. An Instron 8874 (Instron, Norwood, MA, USA) testing device was used for failure testing. A stainless steel ball with a diameter of 6 mm was fixed to the upper crosshead of a universal testing machine and positioned upon the tested crown. The vertical load was aligned with the tooth's axis. Due to the radius of the sphere, the contact points were

located adjacent to the central fossa. A 0.2 mm thick rubber foil was positioned between the crown and the sphere in order to reduce peak stresses at the contact points. A compressive load was applied at a crosshead speed of 2 mm/min, and failure was recorded.

3. Results

The crack was observed in the monolithic crowns after the ultimate failure of the crown. Therefore the crack propagation could not be determined visually, but in all cases the origin was on the occlusal surface.

Digital images of the crowns fragments were used to verify the pieces in all cases. The final fracture occurred after cracks, splitting the crown into two and or more parts, with or without fracture of the composite die. In the majority of cases (samples V1, V4, V7, C2, C3, C4, C5, C7, C8) final fracture occurred by splitting through the crown and composite die into two or more parts. The splitting line was centric or eccentric. The splits deviated slightly from the fissure plane, suggesting that fracture may find a path through the cusps (in case of centric split) (Figure 1) or along the fissure (in case of eccentric split) (Figure 2). In these cases the crown failure appeared to be abrupt at the critical load, with no visible sign of precursor cracking prior to splitting. Other cases are characterized by fractures of the crown associated with fissure in the composite die (samples, V5 and C1) (Figure 3), crown fractures (samples V2, V3, V6, C6) (Figure 4) or only cracks in the crowns, mostly radially (sample V8) (Figure 5). For Cergo samples fractures were more critical.

The graphically correlation of the displacement with the load highlights a series of peaks which could be associated with crown cracks (Figure 6). An increased number of peaks are associated with multiple fragments of the fractured samples.

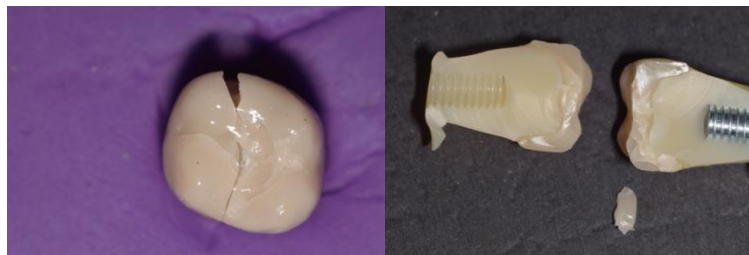


Figure 1. Centric splitting of the crown and underlying die (sample V1).



Figure 2. Eccentric splitting of the crown and underlying die (sample C3).



Figure 3. Eccentric splitting of the crown and cracking of the die (sample V5).

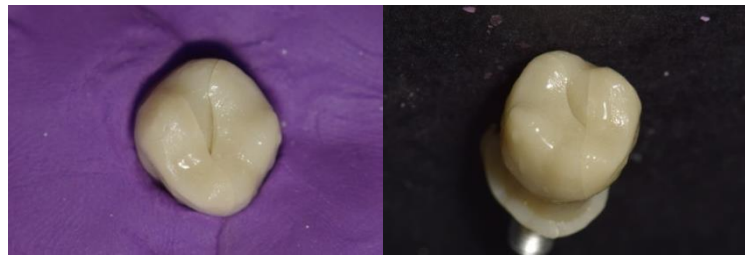


Figure 4. Fracture of the crown (sample C6).



Figure 5. Chipping of the crown (sample V8).

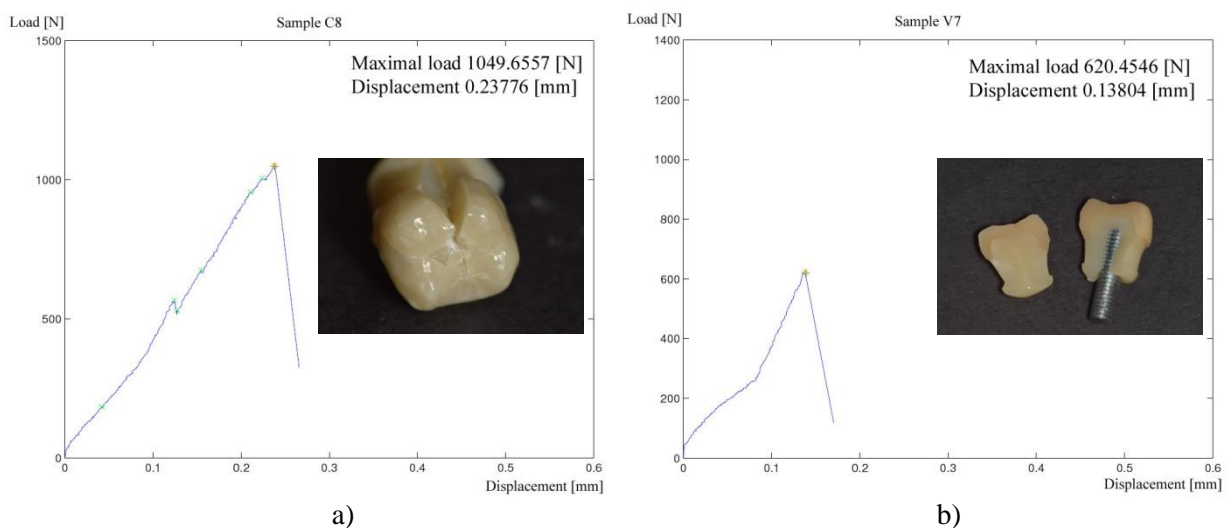


Figure 6. Graphical representation recorded during mechanical compression tests: a) multiple peaks for sample C8, correlated with cracks in the ceramic crown, and fracture of the die, b) single peak for sample V7, correlated with a fracture line in the ceramic crown, and fracture of the die.

The maximal loads registered for each sample can be correlated with the displacements. The mean values were 918.16 N, and 0.21 mm for Cergo samples, 866.20 N, and 0.22 mm for Vita samples.

For Vita samples there were greater differences between the studied samples, while at Cergo the fracture values were closer to each other. Between the studied groups, the difference is not significant ($p > 0.05$), their fracture behavior is similar.

4. Discussions

The study examined splitting of anatomically molar crowns, made of hot pressed ceramics, without filler and leucite reinforced. Splitting was induced by axial loading with a sphere placed in the central fossa. Experiments were made on manufactured hot pressed ceramic crowns and critical loads to failure were measured. To simulate clinical conditions, the study used anatomic crowns, instead of disks or bars, bonded to a composite material which presents a mechanical behavior similar to human teeth.

The fracture loads found in this study (620.45 to 1270.35 N) were higher than those of normal human mastication (60 to 250 N) and in most cases even higher than the occlusal forces related to bruxism, tooth clenching, and parafunctions (approximately 800 N) [29,30].

Fatigue behavior could result in slow crack growth from the surface defects over time and contribute to the failure. Therefore, the possibility of chipping or fractures in clinical service is not excluded and can be attributed to the fatigue [31,32]. The main challenge for the design of ceramic restorations includes the estimation of their failure possibility. Other studies show that the strength of a ceramic material is inversely proportional to the square root of the critical size of crack-like defects that are randomly distributed in the material [33]. Due to the position, length and orientation of critical cracks, the strength of ceramics vary unpredictably from component to component, even if identical specimens are tested.

5. Conclusions

Glass ceramics are brittle and fragile materials, and crack initiation and propagation can result in failures of the restorations during functions.

The estimation of the failure probabilities of monolithic ceramic restorations under expected loading conditions is a challenge in this field.

The modes of failure have to be correlated with the type of the material. Within the limitations of this study, the tested hot-pressed monolithic ceramic crowns show similar fracture strength and fracture behavior.

References

- [1] Zhao T, Qin Y, Zhang P, Wang B, Yang J 2014 *Ceram Int* High-performance, reaction sintered lithium disilicate glass-ceramics 40 pp 12449–12457.
- [2] Heintze S D, Cavalleri A, Forjanic M, Zellweger G, Rousson V 2008 *Dent Mater* Wear of ceramic and antagonist- a systematic evaluation of influencing factors in vitro 24 pp 433–449.
- [3] Porojan L, Porojan S, Rusu L, Bolos A, Savencu C 2017 *MATEC Web of Conferences* Edited by: Amir H F A; Khiew P S Experimental Analyses for The Mechanical Behavior of Pressed All-Ceramic Molar Crowns with Anatomical Design, 108, International Conference on Mechanical, Aeronautical and Automotive Engineering (ICMAA), Malacca, Malaysia, UNSP 02001.
- [4] Porojan L, Savencu C, Porojan S 2016 *Revista de Chimie* Applications of Heat-pressed Ceramics for Single Tooth Restorations 67 pp 123-126
- [5] Malament K A, Socransky S S, Thompson V, Rekow D 2003 Survival of glassceramic materials and involved clinical risk: variables affecting long-term survival *Pract Proced Aesthet Dent* (Suppl), S5-S11.
- [6] Skouridou N, Pollington S, Rosentritt M, Tsi trou E, 2013 *Dent Mater* Fracture strength of minimally prepared all-ceramic CEREC crowns after simulating 5 years of service 29 e70-e77.
- [7] Guess P C, Schultheis S, Wolkewitz M, Zhang Y, Strub J R 2013 *J Prosthet Dent* Influence of preparation design and ceramic thicknesses on fracture resistance and failure modes of premolar partial coverage restorations 110 pp 264–273.
- [8] Sieper K, Wille S, Kern M 2017 *J Mech Behav Biomed Mater* Fracture strength of lithium disilicate crowns compared to polymer-infiltrated ceramic-network and zirconia reinforced lithium silicate crowns 74 pp 342-348.
- [9] Christensen G J 1999 *J Am Dent Assoc* Porcelain-fused-to-metal vs nonmetal crowns 130 pp 409-511.
- [10] Zhang Y, Lee JJ-W, Srikanth R, Lawn BR 2013 *Dent Mater* Edge chipping and flexural resistance of monolithic ceramics 29 pp 1201-1208.
- [11] Gehrt M, Wolfart S, Rafal N, Reich S, Edelhoff D 2013 *Clin Oral Invest* Clinical results of

- lithium-disilicate crowns after up to 9 years of service. Ig 17 pp 275-284.
- [12] Pieger S, Salman A, Bidra AS 2014 *J Prosthet Dent* Clinical outcomes of lithium disilicate single crowns and partial fixed dental prostheses: a systematic review 112 pp 22-30.
 - [13] Zesewitz TF, Knauber AW, Northdurft F P 2014 *Int J Prosthodont* Fracture resistance of a selection of full-contour all-ceramic crowns: an in vitro study 27 pp 264-266.
 - [14] Johansson C, Cmet G, Rivera J, Larsson C, Vuit Von Steyern P 2014 *Acta Odontol Scand* Fracture strength of monolithic all-ceramic crowns made of high-translucent yttrium-oxide-stabilized zirconium dioxide compared to porcelain-veneered crowns and lithium disilicate crowns 72 pp 145-153.
 - [15] Magne P, Carvalho AO, Bruzi G, Giannini M 2015 *J Prosthet Dent* Fatigue resistance of ultrathin CAD/CAM complete crowns with a simplified cementation process 114 p 574-579.
 - [16] Fasbinder DJ, Dennison J B, Heys D, Nelva G 2010 *J Am Dent Assoc* A clinical evaluation of chairside lithium disilicate cad/cam crowns: a two-year report 141 10S-4
 - [17] Kern SM, Sasse M, Wolfart S 2012 *J Am Dent Assoc* Ten-year outcome of three-unit fixed dental prostheses made from monolithic lithium disilicate ceramic 143 pp 234-240.
 - [18] Reich S, Schierz O 2013 *Clin Oral Investig* Chair-side generated posterior lithium disilicate crowns after 4 years 17 pp 1765-1772.
 - [19] Zhang Y, Mai Z, Barani A, Bush M, Lawn B 2016 *Dent Mater* Fracture-resistant monolithic dental crowns 32 p 442-449.
 - [20] Mores R T, Borba M, Corazza P H, Della Bona Á, Benetti P 2017 *J Prosthet Dent* Influence of surface finishing on fracture load and failure mode of glass ceramic crowns 118 pp 511-516.
 - [21] Mora G P, O'Brien W J 1994 *J. Biomed. Mater. Res.* Thermal shock resistance of core reinforced all-ceramic crown systems 28 pp 189-194.
 - [22] Dimitrijević M, Pošarac M, Jančić-Heinemann R, Majstorović J, Volkov- Husović T, Matović B 2008 *Appl. Ceram.* Thermal shock resistance of ceramic fibre composites characterized by non-destructive methods, process 2 pp 115-119.
 - [23] Silva TM, Salvia AC, Carvalho RF, Pagani C, Rocha DM, Silva EG 2014 *J Prosthodont Res* Polishing for glass ceramics: which protocol? 58 p 160-170.
 - [24] Benetti P, Kelly J R, Della Bona A 2013 *Dent Mater* Analysis of thermal distributions in veneered zirconia and metal restorations during firing 29 p 1166-72.
 - [25] Swain M V 2009 *Acta Biomater* Unstable cracking (chipping) of veneering porcelain on all-ceramic dental crowns and fixed partial dentures 5 pp 1668-1677.
 - [26] Sailer I, Makarov N A, Thoma D S, Zwahlen M, Pjetursson B E 2015 *Dent Mater* All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part I: single crowns (SCs) 31 pp 603-623.
 - [27] Brunot-Gohin C, Duval J L, Azogui E E, Jannetta R, Pezron I, Laurent-Maquin D, Gangloff SC, Egles C. 2013 *Dent Mater* Soft tissue adhesion of polished versus glazed lithium disilicate ceramic for dental applications 29 e205-212.
 - [28] Scherrer SS, Quinn JB, Quinn GD, Kelly JR 2006 *Int J Prosthodont* Failure analysis of ceramic clinical cases using qualitative fractography 19 pp 185-92.
 - [29] Kelly J R, Benetti P Ceramic materials in dentistry: historical evolution and current practice. *Aust Dent J* 2011;56 (Suppl 1) pp 84-96.
 - [30] Brunot-Gohin C, Duval JL, Azogui EE, Jannetta R, Pezron I, Laurent-Maquin D, et al. 2013 *Dent Mater* Soft tissue adhesion of polished versus glazed lithium disilicate ceramic for dental applications 29 e205-12.
 - [31] Mores R T, Borba M, Corazza P H, Della Bona Á, Benetti P 2017 *J Prosthet Dent* Influence of surface finishing on fracture load and failure mode of glass ceramic crowns 118 p 511-516.
 - [32] Scherrer S S, Quinn J B, Quinn G D, Wiskott H W 2007 *Dent Mater* Fractographic ceramic failure analysis using the replica technique 23 p 1397-404.
 - [33] Serkan N, Chunsheng L 2012 *Ceram Int* Fracture statistics of dental ceramics: Discrimination of strength distributions 38 pp 4979-4990.