Evaluation of areas susceptible to failure in hot-pressed ceramic crowns

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Abstract: Fracture of ceramic materials has been one of the most frequently reported complications for all-ceramic restorations. The aim of the study was to analyze the fracture features of hot-pressed ceramic crowns in order to evaluate areas susceptible to crack initiation and crack propagation correlated with stress areas. The crowns were inspected visually to determine the shape and orientation of the crack. The fracture surfaces of each restoration were documented with photographs of fractographic features and were examined using scanning electron microscopy. The starting point and crack propagation were determined using standard fractographic methods. A systematic approach to failure analysis is important in order to interpret failure data for all categories of ceramic restorations available today. Further studies of clinically relevant fracture testing and other experimental simulation methods are necessary in order to suggest different strategies for restoration design, and tooth preparation.

Key-Words: hot-pressed ceramics, crown, fracture features, crack propagation, scanning electron microscopy.

1 Introduction

The clinical success of all-ceramic restorations and the increase in patient demand for an aesthetic treatment results in the development and introduction of many all ceramic systems. However, fracture of ceramic materials has been one of the most frequently reported complications for all-ceramic restorations. Fracture of brittle materials, like ceramics, typically causes from a crack propagation[1].

Failure analysis includes examination of the fractured components in order to investigate the cause of failure, and to correlate with a design, material, technological deficiency (fabrication process) or in situ stress-induced conditions. The description and interpretation of fracture markings used to understand failure events of brittle materials are very important.

The key tools for performing fractography on failed parts are the binocular stereomicroscope and the scanning electron microscope (SEM). The SEM is an excellent analysis tool allowing high resolution close-ups of predetermined regions of interest [2].

Fractographic analysis is the study of fracture surface topography of brittle materials which contains specific characteristic markings. These markings can be used to identify the fracture origins, fracture path and mechanisms of failure. It can also be used to estimate the stress at failure when stress is typically not measurable [3].

There have been few studies that used the quantitative fractography as an analytical tool to find the failure initiation sites and also to estimate the in vivo failure stress of ceramic restorations [4,5].

Definitions of the most common fracture surface features visible in dental ceramics are summarized below for better understanding of the failure analyses.

Fracture mirrors are relatively smooth regions surrounding and centred on the fracture origin. The fracture mirror is the region where a crack radiates outwards from a flaw at the fracture origin.

A hackle is a line on the surface running in the local direction of cracking, separating parallel, but noncoplanar portions of the crack surface.

An arrest Line is a sharp line on the fracture surface defining the crack front shape of an arrested or momentarily hesitated crack prior to resumption of crack propagation under a more or less altered stress configuration.
Great stress in the part at fracture is accompanied by much stored energy, and rich fracture markings. Weak parts with low stored energy are often difficult to interpret [6].
A few papers in the dental literature have been published using a standardized approach for failure analysis of fractured different ceramic restorations [7-14].

2 Purpose

The aim of this study was to analyze the fracture features of hot-pressed ceramic crowns in order to evaluate areas susceptible to crack initiation and crack propagation correlated with stress areas.

3 Materials and Method

Specific steps were covered in order to obtain heat pressed ceramic crowns using Cergo pressed ceramics (Degudent, Hanau, Germany). The crowns were glazed and conventionally cemented. All specimens were mounted in a universal testing machine Dynamic Multipurpose Testing System series LFV (walter+bai ag Löhningen, Switzerland).and subject to failure tests. A thin rubber foil of 0.2 mm was inserted between the tested crowns and the antagonists in order to reduce peak stresses at the contact points.
The fracture surface topography of hot-pressed ceramic crowns were examined using scanning electron microscopy. They were inspected for fractographic features such as hackle, and arrest lines, for determination of the direction of crack propagation in relation to the origin.
Surfaces were not destroyed by handling were the object of interest.
The crowns were inspected visually to determine the shape and orientation of the crack. Analyses were performed with a SEM microscope - Inspect S (FEI Company, Hillsboro, Oregon, USA).
The fracture surfaces of each restoration were documented with photographs of fractographic features. The starting point and crack propagation were determined using standard fractographic methods. [15-17].
The crack propagation was determined according to the direction of those features.

4 Results and Discussions

Several arrest lines and hackle became clearly visible on the chip. Greater magnifications under the SEM confirmed the presence of these features including wake hackle which are good indicators of the direction of crack propagation (dcp).
The exact origin of the crack is located at the loading area (generated during experimental tests) and from there a critical crack started and propagated along the axial and occlusal walls until fracturing the whole crown into two parts, used for the fractographic analysis (Fig. 1, 4).
Using the SEM, the concave orientation of the arrest lines as well as the presence of many fine twist hackle emanating from the arrest lines indicated that the damage started on the occlusal loading surface of the crown (Fig. 2, 3, 5, 6).

Fig. 1. Fracture surface of a pressed ceramic crown specimen exposing fracture origin on the occlusal loading point and the fractographic map.

Fig. 2. Scanning electron microscopy images of one fragment of a pressed ceramic crown (black arrow indicates the loading point).

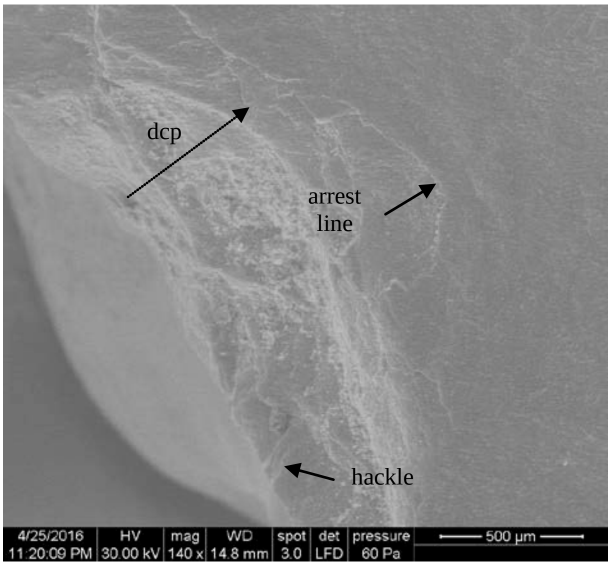

Fig. 3. Scanning electron microscopy images of one fragment of a pressed ceramic crown with higher magnification of the fractographic map.

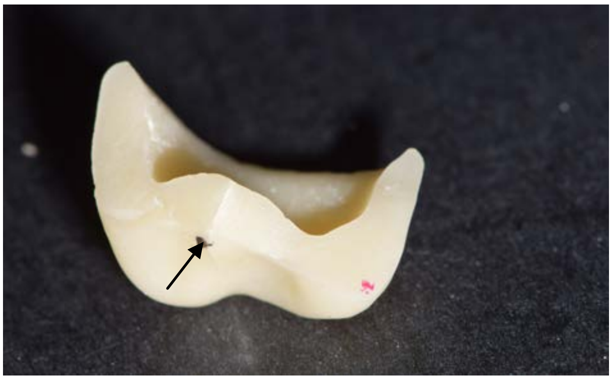

Fig. 4. Fracture surface of a pressed ceramic crown specimen exposing fracture origin on the occlusal loading point and the fractographic map.

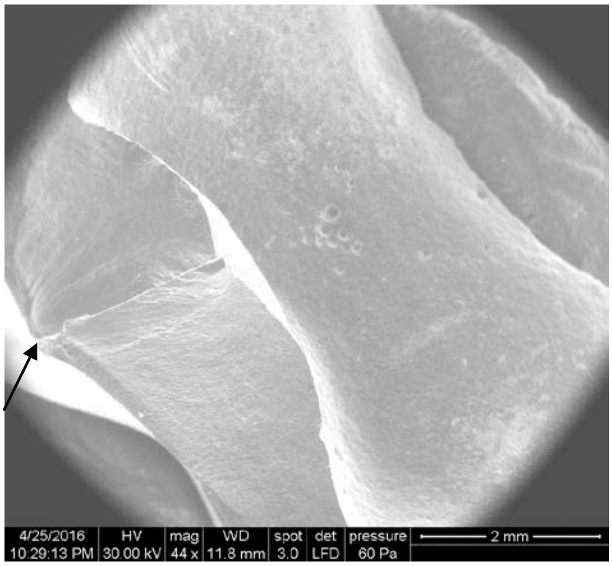

Fig. 5. Scanning electron microscopy images of one fragment of a pressed ceramic crown (black arrow indicates the loading point).

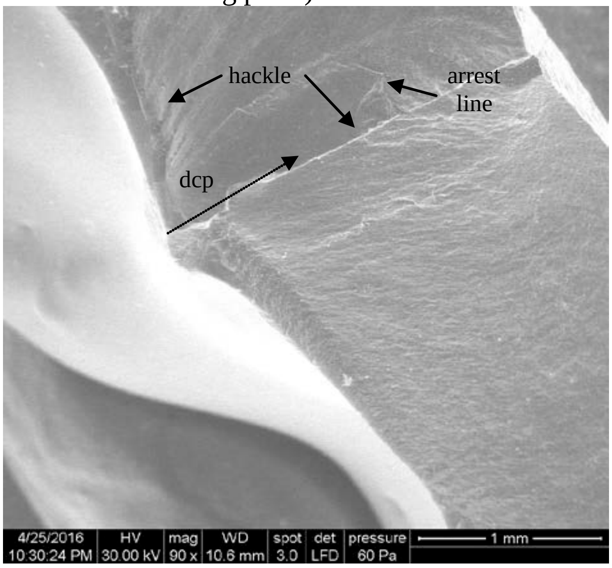

Fig. 6. Scanning electron microscopy images of one fragment of a pressed ceramic crown with higher magnification of the fractographic map.

The visual examination is a crucial step for setting the fractographic foundation for the SEM analysis. The SEM however will provide more easily the high power images of fine details such as wake hackle and twist hackle. The force direction has been confirmed by fractographic markings such as hackle and wake hackle [2].

A systematic approach to failure analysis is important in order to interpret failure data for all categories of ceramic restorations available today. At the current state, dentists and scientist should work together to collect available clinical data and to make experimental analyses [2].

All have to be correlated with other experimental methods, like numerical simulations, where high stresses were recoded around the contact areas with the antagonists (Fig. 7), areas susceptible to failure.

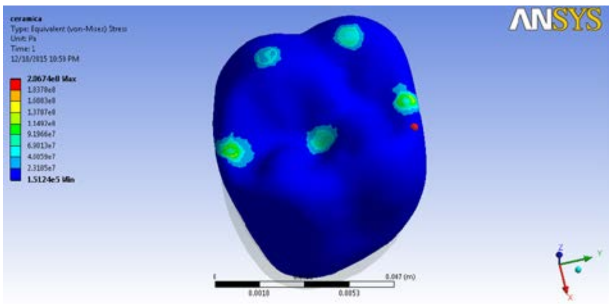

Fig. 7.Stresses recorded in a ceramic crown.

The study is important for understanding fracture processes in brittle restorative materials and, to draw conclusions as to possible design inadequacies in failed restorations [11].

5 Conclusions

Within the limitations of the present study, the following conclusions can be drawn:

1. The fractographic analyses of single tooth restorations indicate that the weakest point is at the loading point.
2. Further studies of clinically relevant fracture testing and other experimental simulation methods are necessary in order to suggest different strategies for restoration design, and tooth preparation.
3. Failure analyses results can provide design guidelines for new and varied aesthetic crowns, in order to withstand functional loads in the posterior areas.

6 Acknowledgements

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation CNCS-UEFISCDI, project number PN-II-RU-TE-2014-4-0476.

References:

[1] Triwatana P, Srinuan P, Suputtamongkol K. Comparison of two fracture toughness testing methods using a glass-infiltrated and a zirconia dental ceramic. *J Adv Prosthodont.* 2013 Feb;5(1):36-43.

[2] Scherrer SS, Quinn GD, Quinn JB. Fractographic failure analysis of a Procera AllCeram crown using stereo and scanning electron microscopy. *Dent Mater.* 2008, Aug;24(8):1107-13.

[3] Scherrer SS, Kelly JR, Quinn GD, Xu K. Fracture toughness (KIc) of a dental porcelain determined by fractographic analysis. *Dent Mater* 1999;15:342-8.

[4] Taskonak B, Mecholsky JJ Jr, Anusavice KJ. Fracture surface analysis of clinically failed fixed partial dentures. *J Dent Res* 2006;85:277-81.

[5] Oh WS, Park JM, Anusavice K. Fracture toughness (KIC) of a hot-pressed core ceramic based on fractographic analysis of fractured ceramic FPDs. *Int J Prosthodont* 2003;16: 135-40.

[6] Quinn. GD, Fractography of Ceramics and Glasses, Materials Science and Engineering Laboratory, National Institute of Standards and Technology Special Publications, 2007.

[7] Fischer H, Gröbel J, Marx R. Fraktographische Schadensanalyse an Dentalkeramik. *Dtsch Zahnärztl Z* 2000;55:667–70.

[8] Quinn JB, Quinn GD, Kelly JR, Scherrer SS. Fractographic analyses of three ceramic whole crown restoration failures. *Dent Mater* 2005;21(10):920–9.

[9] Scherrer SS, Quinn JB, Quinn GD, Kelly JR. Failure analysis of ceramic clinical cases using qualitative fractography. *Int J Prosthodont* 2006;19(2):185–192.

[10] Taskonak B, Mecholsky JJ Jr, Anusavice KJ. Fracture surface analysis of clinically failed fixed partial dentures. *J Dent Res* 2006;85:277–81.

[11] Scherrer SS, Quinn JB, Quinn GD, Wiskott HWA. Fractographic ceramic failure analysis using the replica technique. *Dent Mater* 2007;23(11):1397–1404.

[12] Scherrer, SS.; Quinn, JB.; Quinn, GD.; Wiskott, HWA. Descriptive Fractography on All Ceramic Dental Crown Failures. In: Varner, James R.; Quinn, George D.; Wightman, Marlene, editors. Fractography of Glasses and Ceramic V, Ceramic Transaction. 199. The American Ceramic Society, John Wiley & Sons; Hoboken, New Jersey: 2007. p. 339-350.

[13] Quinn, JB.; Scherrer, SS.; Quinn, GD. The Increasing Role of Fractography in the Dental Community. In: Varner, James R.; Quinn, George D.; Wightman, Marlene, editors. Fractography of Glasses and Ceramic V, Ceramic Transaction. 199. The American Ceramic Society, John Wiley & Sons; Hoboken, New Jersey: 2007. p. 253-270.

[14] Taskonak, B.; Yan, J.; Mecholsky, JJ, Jr. Fracture Surface Analysis of Dental Ceramics. In: Varner, James R.; Quinn, George D.; Wightman, Marlene, editors. Fractography of Glasses and Ceramic V, Ceramic Transaction. 199. The American Ceramic Society, John Wiley & Sons; Hoboken, New Jersey: 2007. p. 271-279.

[15] Øilo M, Hardang AD, Ulsund AH, Gjerdet NR. Fractographic features of glassceramic and zirconia-based dental restorations fractured during clinical function. *Eur J Oral Sci* 2014; 122: 238–244.

[16] Øilo M, Gjerdet NR. Fractographic analysis of all-ceramic crowns: a study of 27 clinically-

fractured crowns. *Dent Mater* 2013; 29: e78–e84.

[17] American Society for Testing and Materials. 1322-02 AC. Standard practice for fractography and characterization of fracture origins in advances ceramics. Annual book of ASTM standards. Vol. 15.01. West conshocken, PA, Philadelphia: American Society for Testing and Materials, 2002.