Experimental analysis of areas susceptible to fracture in hot-pressed ceramic crowns

L. Porojan, S. Porojan, M. Bîrdeanu, C. Savencu, A. Cernescu and F. Topală

***Abstract*—**Fracture is reported as the most frequently complication for all-ceramic restorations. The aim of the study was to analyze the experimental fracture features of hot-pressed ceramic crowns in order to evaluate areas susceptible to crack initiation and crack propagation. The experimental fractured 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. The failure areas were correlated with stress areas identified after finite element analyses. Further studies of fracture testing and other experimental simulation methods are necessary in order to suggest different strategies for restorations design, and teeth preparations.

***Keywords*—** crack propagation, crown, finite element analysis, fracture, hot-pressed ceramics, scanning electron microscopy.

I. 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 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.

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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 contain 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 no coplanar 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].

New ceramic materials are often introduced into the market without a basic understanding of their clinical performance because long term controlled clinical trials are not required and are both time-consuming and expensive. The development of experimental methods could be useful to help predict clinical behaviour of these new restorative materials [15].

Finite element analysis (FEA) is a powerful and flexible computational tool to model dental structures and devices, simulate the occlusal loading conditions and predict the stress and strain distribution. It has been widely used in the dental and medical fields since the 1970s and has been proven to be accurate and efficient for finding solutions for complex geometry problems [16, 17].

II. 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. .

III. 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 was 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 [18]-[20].

The crack propagation was determined according to the direction of those features.

For the numerical simulations, using the finite element method, the teeth were designed with a preparation for full-coverage crowns according to the guidelines of the prosthetic material manufacturers. The preparation included a 1.5-mm occlusal reduction, a 1.0 mm axial reduction, a 6-degree angle of taper, a 1-mm circular chamfer shoulder. The restorative material for monolithic dental crowns was hot-pressed glass-ceramic.

Geometric models of the monolithic crowns were designed to occupy the space between the original tooth form and the prepared tooth form. At first nonparametric modeling software (Blender 2.57b) was used to obtain the 3D tooth shapes. The collected data were used to construct three dimensional models using Rhinoceros (McNeel North America) NURBS (Nonuniform Rational B-Splines) modeling program. The geometric models were imported in the finite element analysis software ANSYS (Fig. 1), meshed (Fig. 2) and finite element calculations were carried out.

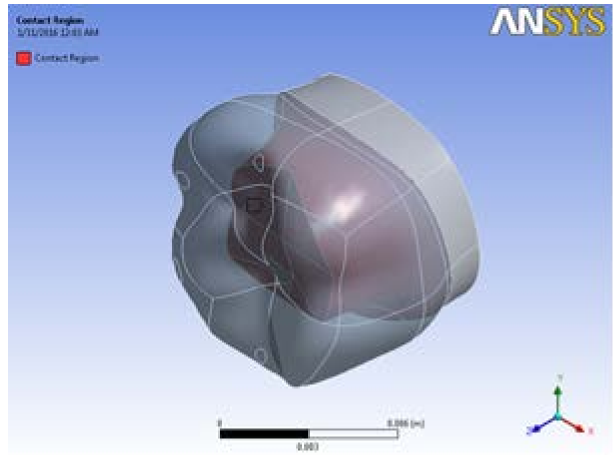

Fig. 1. Geometrical model of the restored molar.

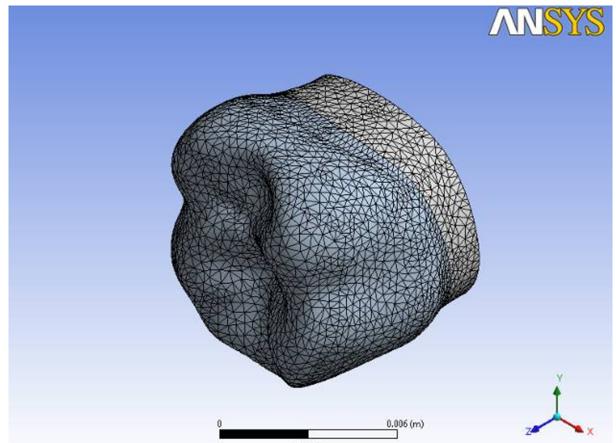

Fig. 2. Finte element model of the restored molar.

The finite element model was solved under a variety of load case-material property combinations. The nodes on the bottom surface of the abutment tooth were constrained in all directions.

The crown materials were assigned using literature data. In order to simulate the stress distribution, the Young's module and Poisson's ratios were introduced: Young's modulus (GPa) 18 for dentin, 64 for pressed ceramic, and Poisson's ratio 0.27 for dentin, 0.21 for pressed ceramic. The load was applied a maximum bite force of 800 N for molars (Fig. 3). Generally it is assumed that the materials used in the models are linearly elastic, homogeneous, and isotropic, but they had different compressive and tensile strengths. Unfortunately, the properties of tooth structures are not homogeneous and are anisotropic like dentin or enamel. Furthermore, during laboratory fabrication of prosthetic crowns some material artifacts can occur that cannot be taken into consideration. The simulated bite force was distributed across contact areas with antagonists. The distribution of the principal stress and the equivalent stress, and also the maximal values were determined.

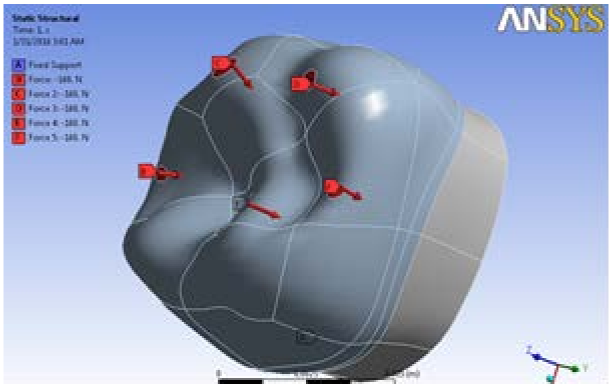

Fig. 3. Loading areas of the molar crown for the finite element analysis.

IV. 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. 4, 7).

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. 5, 6, 8, 9).

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

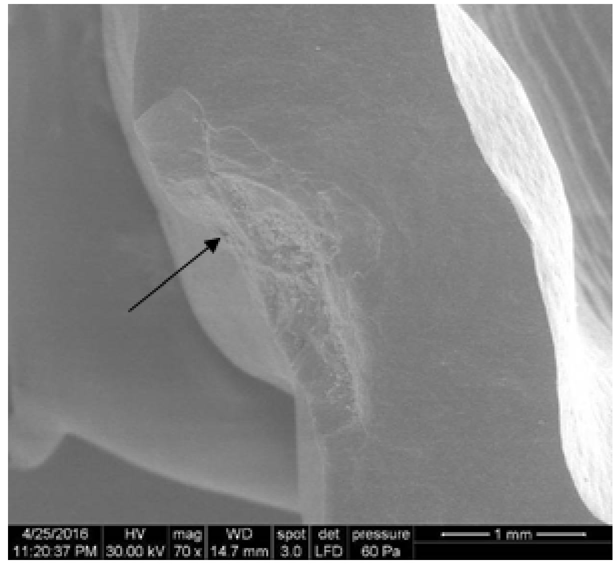

Fig. 5. Scanning electron microscopy images of one fragment of a pressed ceramic crown (black arrow indicates the loading point).

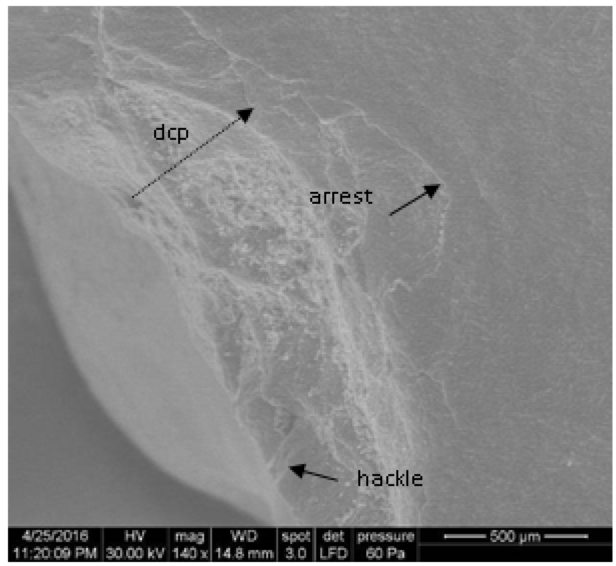

Fig. 6. Scanning electron microscopy images of one fragment of a pressed ceramic crown with higher magnification of the fractographic map.

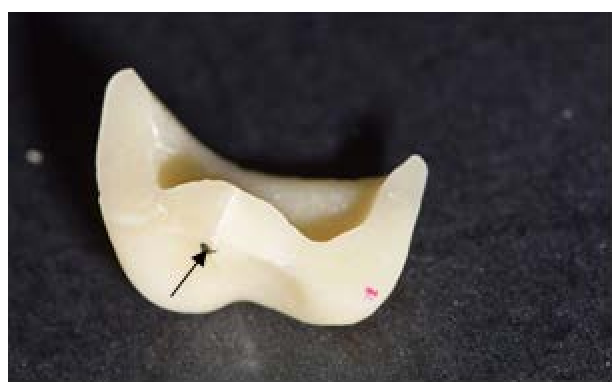

Fig. 7. Fracture surface of a pressed ceramic crown specimen exposing fracture origin on the occlusal loading point and the fractographic map.

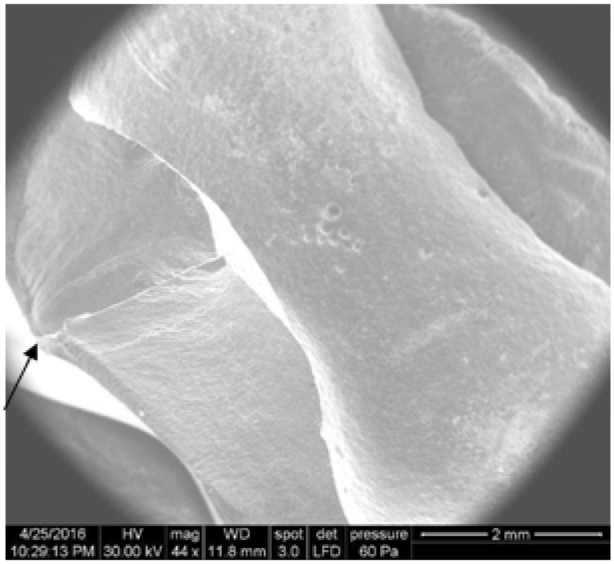

Fig. 8. Scanning electron microscopy images of one fragment of a pressed ceramic crown (black arrow indicates the loading point).

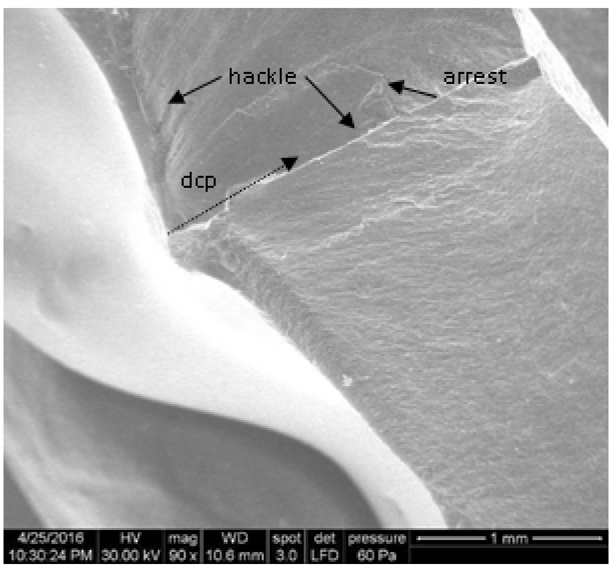

Fig. 9. Scanning electron microscopy images of one fragment of a pressed ceramic crown with higher magnification of the fractographic map.

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 principal stresses were recoded around the contact areas with the antagonists (Fig. 10), and these areas can be starting points for the failure of aesthetic hot-pressed ceramic crowns in the posterior area.

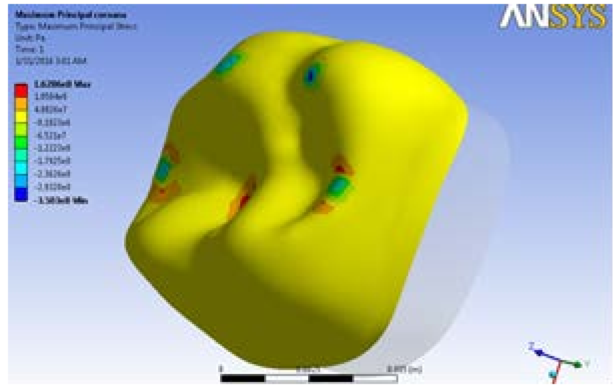

Fig. 10. Principal stresses recorded in a hot-pressed ceramic crown.

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].

V. Conclusions

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

1. The fractographic experimental analyses of single tooth restorations indicate that the weakest point is at the loading point.
2. Finite element analyses stress areas were correlated with those obtained by the experimental fracture tests.
3. SEM analyses provide fine details for understanding the crack starting point and the fracture propagation direction.
4. Failure analyses results can provide design guidelines for new and varied aesthetic crowns, in order to withstand functional loads in the posterior areas.

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