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Thermal shock cycling effect on the compressive behaviour of human teeth

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ABSTRACT

All ceramic veneers are a common choice that both dentists and patients make for anterior restorations. In the framework of the present study the residual compressive behavior of the above mentioned complex structures after being thermally shock cycled was investigated. An exponential decrease in both compressive stiffness and strength with the thermal shock cycle number was observed. Experimental findings were in good agreement with predicted values. Photomicrographs obtained revealed a different failure mechanism for the pristine and cycled teeth, which is indicative of the susceptible nature of restored teeth to thermal shock. A two-dimensional finite element model designed gave a better insight upon the stress fields in response of thermal or mechanical loadings developed in the oral cavity.

1. Introduction

All ceramic veneers are considered as the most esthetic and pleasing prosthodontic restorations. The choice for this material is depended on its ability to resemble the physical, mechanical and esthetic properties of natural tooth structure. Nowadays a great amount of clinicians and patients choose this kind of restorations not only for their esthetic result but also because of the conservative preparation of the hard dental tissues (Castelnuovo et al., 2000; Edelhoff and Ozcan, 2007). Enamel is considered the hardest and most durable tissue in whole body; after its unique formation process it presents lower modulus of elasticity and higher energy absorption than sintered hydroxyapatite material (Li and Michael, 2008). In order to achieve the adhesion with the enamel surface composite resin luting agents are available which can be either light cured, chemically cured or both (Hofmann et al., 2001). These dental adhesives are fabricated to bond the hard dental tissue surface with the restoration material. As all prosthodontics restorations, all ceramic veneers need to serve their functional role in a very demanding and difficult to predict environment such as the oral cavity. Therefore successful bonding of the interphase material, which in this case is the cement, to both ceramic veneer and the enamel surface is vital for the retention of the restoration (Peumans et al., 2000). Stresses developed into the mouth cavity are strongly affected by the combined effect of thermal shock and compressive loading exhibited during mastication. In addition, these stresses have a specific effect on the bond strength developed between the adhesive resin cement and the two main materials; i.e. the enamel, and the all ceramic veneer, resulting in a mechanical degradation of the whole system of materials. Heinz et al. (2006) evaluated the share bond strength between different cements after thermal cycling and found that the strongest bond to zirconia was obtained with resin bonded cement type Panavia F. Moreover, Cantoro et al. (2008) after following the same process also agreed that temperature – pre-heating before using – enhances the bonding potential of Panavia F2.0 composite resin cements. However, the conditions that exist in mouth cavity are related to temperature and stress range and can be in some cases borderline. The aim of this in vitro study was to investigate the compressive behavior of the aforementioned complex structures after thermal shock cycling. The residual strength and stiffness of restored teeth were determined by means of static mechanical tests. Monotonically increasing loads were applied; however, in the oral environment, failure is usually more complex and comes as a result of fatigue, thermal loadings, moisture absorption and degradation related with age, sex, oral hygiene conditions, and other patient-related parameters. The residual strength and stiffness of restored teeth were determined by means of static mechanical tests. Monotonically increasing loads were applied; however, in the oral environment, failure is usually more complex and comes as a result of a fatigue, thermal loadings, moisture absorption and degradation related with age, sex, oral hygiene conditions, and other patient-related parameters.

In the present investigation, experimental findings were combined with analytical and numerical modelings. The main contribution in the present work is the successful application of the analytical model,

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named Residual Property Model (RPM), developed by the first author, to predict the degradation of the mechanical strength and stiffness of the dental materials tested when subjected to thermal fatigue loading. In addition, a finite element model corresponding to the geometry of a restored incisor was developed. The subdivision of the model into small elements resulting in a mesh where the mechanical properties of the constituent materials and applied compressive and thermal loadings are given allowed the determination of the stress distribution as well as of the regions of high stress concentrations. In these very regions fracture of the restoration is expected to initiate due to crack nucleation and propagation. Photomicrographs of fractured areas corroborated the results of FEM analysis concerning the predominant mechanisms of failure initiation, both for the cycled and pristine teeth.

2. Materials and methods

2.1. Teeth restoration

Eight human non-carious central incisors were collected and sterilized in 0.5% Cloramine solution, cleaned from the soft tissues and stored in distilled water. The teeth were slightly prepared following the requirements of all ceramic veneer preparation design. In order to achieve that, the enamel surface was dyed with color and then a 0.3 mm depth diamond bur was used so as to prevent penetrating deeper the enamel. The reduction followed the anatomic contours of each incisor. The chamfer diamond was placed so as to achieve the "long chamfer" margin which exposes the enamel prisms ends and makes the etching procedure better. The incisal edge was not reduced and in order to prevent stresses all prepared surfaces were rounded. For each specimen a veneer was fabricated to achieve perfect passive marginal fit of the restoration. The resin cement type Panavia was used according to the manufacturer's guidelines. Etching was succeeded with orthophosphoric acid 37% applied to enamel surface. An etching factor HF (hydrofluorade) 9% was applied to the ceramic surface for 10 s. Then the HF was softly removed and silane agent was poured on the etched surface of the ceramic. Primer and bonding agent (liquid A HEMA, liquid B aminolicylic acid) were spread out for 30 s and dried gently with air. By mixing paste A and paste B the chemical cure began and after applying the cement on both surfaces and placing the restoration in place, the light cure followed. The teeth were weighted and all dimensions were measured. Dimensions measured were the mesiodistal and of the clinical crown height. No dimensional changes were found during thermal cycling test.

2.2. Thermal shock cycling

After the adhesion process was completed it was followed by the thermal shock cycling procedure, in order to simulate the thermal loads developed in the oral cavity during mastication or ingestion. The temperature profile of each cycle can be observed in Fig. 1(a). According to this profile, each cycle corresponds to the sequence from room temperature to 80° C and back to room temperature, which corresponds to a variation of 55° C. The total duration of each cycle was of 20 min. The thermal cycling was repeated for 10, 20 and 30 cycles. After the thermal shock cycling process was completed all teeth were weighted and their dimensions were measured again in order to detect any possible weight loss or deformation. Both cycled and pristine teeth were then tested in compression at room temperature.

2.3. Mechanical testing

Prior to mechanical testing, incisors were vertically immersed in photo-polymerized acrylic resin type Vertex S.A just below the tooth's crown inside special molds in order to be mounted in the testing machine. After the resin was polymerized all degrees of freedom were restricted and thus a cantilever was formed. After post-curing took place for 24 h at room temperature, all teeth were tested in compression with a constant crosshead speed of 0.5 mm/min. The normal compressive strain and stress were calculated with respect to the crown length and on the basis of an ellipsoidal cross-section, the dimensions of which were measured with an accuracy of 20 μm.

2.4. Optical microscopy

The topography of fracture surfaces was observed by means of a Leica M125 Stereomicroscope with magnification capacity from 8 × to 100 ×.

2.5. Analytical modeling

In the present investigation experimental results were compared with the respective theoretical predictions as derived from the RPM model, by Papanicolaou et al. (2006a), (2006b). The Residual Property Model (RPM) has been proved to successfully predict a material's residual property (Papanicolaou et al., 2006a, 2006b) irrespective of its nature or the source of damage. The model's basic assumption is that the material's mechanical degradation follows an exponential law of variation. In the present case the residual property after thermal shock cycling is given by

$$\frac{P_r}{P_0} = s + (1-s)e^{-sM} \tag{1}$$

Where

$$s = \frac{P_0}{P_\infty},\ M = \left[\left(\frac{\Delta T}{T_g - T_R}\right)\cdot N\right]/c \tag{2}$$

And

P_0: property of the pristine material.
P_∞: residual property after infinite thermal shock cycles.
P_r: residual property after given thermal shock cycles.
c: number of cycles after which the damage initiates.
N: number of thermal shock cycles.
T_g: the glass transition temperature.
T_R: reference temperature (Room temperature in the present case, 25 °C).

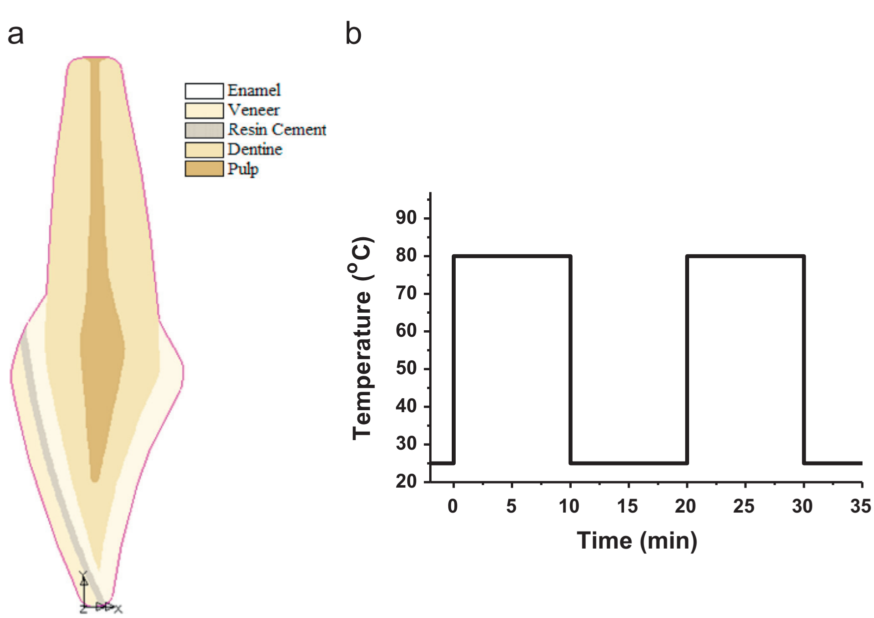

Fig. 1. (a) Geometry of the model and (b) Thermal shock cycling profile.