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PHOTOELASTIC AND FINITE ELEMENT STRESS ANALYSIS OF HUMAN TEETH

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ABSTRACT

In this study, both the photoelastic, as well as the finite element methods, are used to study the stress distribution within various human teeth (mandibular first molar, mandibular central incisor and maxillary central incisor) under forces similar to those that occur during chewing. Two-dimensional models of teeth were created by the software AutoCAD using Wheeler's dental anatomy text book. The coordinates obtained from the Wheeler's data were fed into a computer numerical control (CNC) machine to fabricate the models from photoelastic sheets. Completed models were placed in a transmission polariscope and loaded with static force (55N) at 0° and 45° to the tooth axis. Stress can be quantified and localized by counting the number of fringes. In both methods the Principle stresses were calculated at different regions, the crown, the cervical and the root. It was found that when the tooth subject to the vertical loads, the stresses was concentrated on the cervical region except in the maxillary incisor stress located at crown region. The change of the force angulation (45° to the long axis) increased the level of maximum stresses drastically however; the location of maximum stresses was similar. The numerical results have been compared with the experimental method using photoelasticity pattern which shows good agreement between experimental and simulation results.

Keywords: Photoelasticity, Stress, Load, finite element

1. INTRODUCTION

Teeth are mainly mineralized structures, situated in the initial section of the digestive system. Human teeth are distributed in the maxilla and mandible. Each tooth is naturally divided into two regions: a root and a crown. "The transition from crown to root takes place at the cervix or neck of the tooth in a sinuous outline, and is called the cervical line [1]. Human teeth act as a mechanical device during masticatory processes such as cutting, tearing, and grinding of food particles [2]. Normal mastication with its varying magnitude and direction generates considerable reactionary stress in teeth [3]. The stress on dental structures has been studied using numerous techniques: the brittle shell method, holography, two and three dimensional photoelasticity, the finite element analysis and other methods [4].

Farah et al. [5] compared the photoelasticity method with the finite element method and concluded that these two techniques allow for a better understanding of the distribution of the stresses. Photoelasticity is an experimental technique that uses light to study the physical effects resulting from the action of stresses or deformations in transparent elastic bodies and is used in studies of structures with complicated forms, complex load, distributions or both [6].

The purpose of this study was to analyze, by means of the transmission photoelasticity and the finite element methods, the stresses generated by various human teeth when subjected to a compressive mastication load.

2. MATERIALS AND METHODS

2.1 Photoelastic method:

Photoelasticity is based on the stress- optic effect, which for plane stress analysis is governed by the following stress-optic law [7]:

$$\sigma_1 - \sigma_2 = \frac{N f_a}{h} \qquad (1)$$

Where (N) represent the number of fringes, (f_a) is the material fringe constant and ($\sigma_1 - \sigma_2$) is the difference in the principle stresses, (h) is the thickness of the model [7]. The equation (1) developed for the stress optic law at normal incidence, if the model rotates aboutσ_1 axis by an amount in this case the equation become:

$$\sigma_1 = \frac{f_a \cos\theta}{h \sin\theta^2} (N_\theta - N_0 \cos\theta) \qquad (2)$$

$$\sigma_2 = \frac{f_a}{h \sin\theta^2} (N_\theta \cos\theta - N_0) \qquad (3)$$

By employing Eq. (2) and (3) together with fringes pattern from one normal-and one incidence photograph, it is possible to separate the principle stresses [8].

2.1.1 photoelastic Models

Three types of two-dimensional models of human teeth were fabricated:

• Model (I) maxillary central incisor.

• Model (II) mandibular central incisor.

• Model (III) mandibular first molar.

Model fabrication was done using outline of human teeth obtained from Wheeler’s dental anatomy text book. The coordinates obtained from Wheeler’s data were fed into a computer numerical control (CNC) machine to fabricate the models from polycarbonate plastic sheet. These models cut with a cold water jet. The water jet process created smooth edges and left very little residual stress on the models (Figure 1, 2 and 3)

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Fig. 1 Model of maxillary central incisor

Fig. 2 Model of mandibular central incisor

Fig. 3 Model of mandibular first molar

2.1.2 Experiments

A Transmission circular polariscope was used as the experimental instrument. It consists of a light source, two polarizing plates, and a quarter-wave plate (Fig.4) [9].

Fig. 4 Transmission circular polariscopeand loading frame.

Before loading procedures were initiated, the models were placed in the polariscope to determine if any stress was produced during model preparation. In the loading test, a vertical and static force of 55N at an angle of 0° and 45°to the tooth axis was applied. The stress distributions in the loading models were observed and photographed.

The photoelastic polycarbonate used was calibrated and had an optical Constant of 6.8 N/mm fringe.

2.2 finite element models:

Three types of two dimensional human teeth (maxillary central incisor, mandibular central incisor, and mandibular first molar) were created at Autodesk Inventor CAD system, using common geometry and material properties of the photoelasticity models (E=2.3GPa, υ=0.35). Then, CAD models are imported to the ANSYS software (V.12). The finite element mesh was obtained using a plane quadrilateral element with four nodes. Mesh were pre-analyzed and refined on the stress concentration region. Table1 shows the number of knots and elements used in the whole models

Table 1. The number of nodes and elements for each tooth obtained from ANSYS.

Type of teeth	Number of element	Number of node
Maxillary incisor	585	1080
Mandibular molar	450	810
Mandibular incisor	891	1635

3. RESULTS

The photoelastic analysis and the finite element method were used to assess and compare the distribution of stress in the maxillary central incisor, mandibular central incisor and mandibular first molar.

Under 55N vertical loading, the following findings were recorded from the numerical results of the F.O. of experimental models:

1) Mandibular first molar: the stresses were concentrated in the cervical area (FO =5), the crown regions had moderate stresses (FO = 4) while root had small stress (FO =2), Figure (5a).

2) Maxillary central incisor: Local stress concentrations in the crown area (FO =9), the cervical and root regions had low stress (fringe order=4, 3 respectively) Figure (5a).

3) Mandibular central incisor: the stresses were evenly and symmetrically distributed in the crown area (FO = 5) .The cervical region had high stress concentration (FO=6), root had low stress (FO=3) Figure (5a).

Under oblique loading, the following findings were recorded:

1) Mandibular first molar: higher stress concentration was recorded in the cervical region (FO = 6). In the crown (FO = 5) and root (FO = 4) regions moderated stresses were observed Figure (6a).

2) Maxillary central incisor: high stress in cervical (FO=6), moderated stresses in crown and root (FO=3.4), Figure (6a).

3) Mandibular central incisor: higher stresses were concentrated in the cervical region load side (FO =8). The moderated

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stresses were recorded in the crown and root regions (FO = 6, 5) Figure (6a).

The same results recorded from finite element method. Figure (5, 6,) show the distribution of the stresses in the three types of human teeth obtained by the two methods.

In order to demonstrate the similarity of the values obtained in the experimental and numerical techniques, a comparison of the values of the principle stresses for each tooth was carried out, according to the regions analyzed (tables 2,3).

4. DISCUSSION

Stress is produced within a structure as a result of load acting upon it. The direction of the load applied and the shape of the structure influence the nature of the distribution of stress within the structure.

In this study, Photoelastic testing was used to provide qualitative solution. Material was used within the elastic region and thus, the stress fields are only dependent on the geometry and loading condition.

It was seen from the fringes that the Stress on the teeth increases drastically, with the inclination of force from vertical direction. However the location of stresses similar except in the maxillary central incisor the location of maximum stresses difference because the location of force applied in oblique case dissimilar that in the vertical case. This result comfit with Shihab A. Romeed, et,al. 2012.

Also in this study finite element used to analyze stress distribution using the same dimension of experimental models, the same mechanical properties and the same loading condition.

The Comparison between experimental and numerical results showed a relatively small difference .There is some possible reasons for these differences between experimental and numerical results. Such as:

May be some error in the calculation of the material fringe constant

The fringe order at contact point is very high because of the localized contact load and, therefore, the fringe order exactly at the contact point can never be measured accurately

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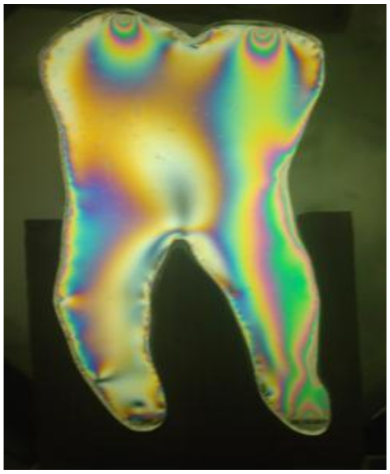

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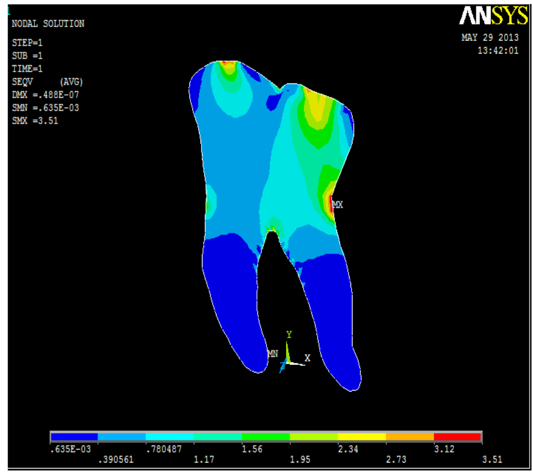

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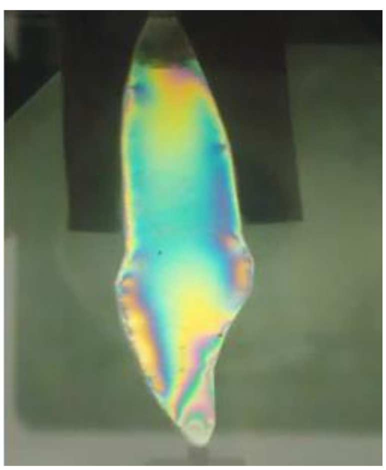

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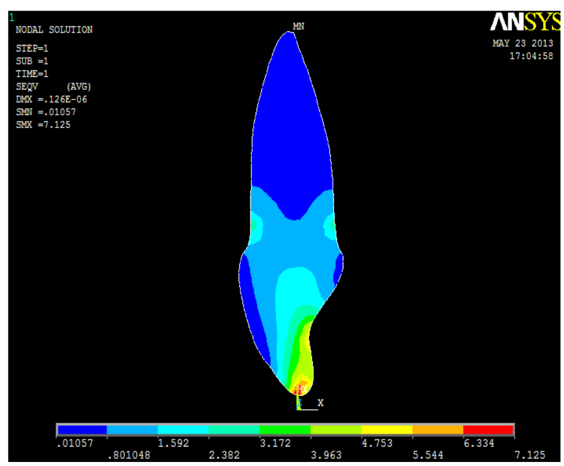

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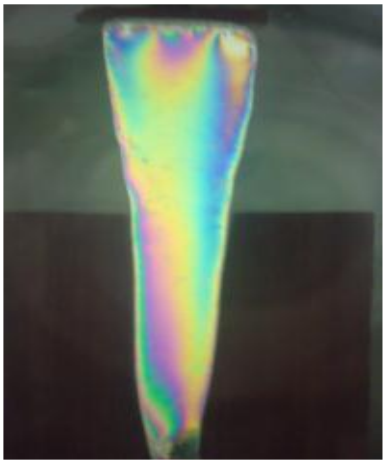

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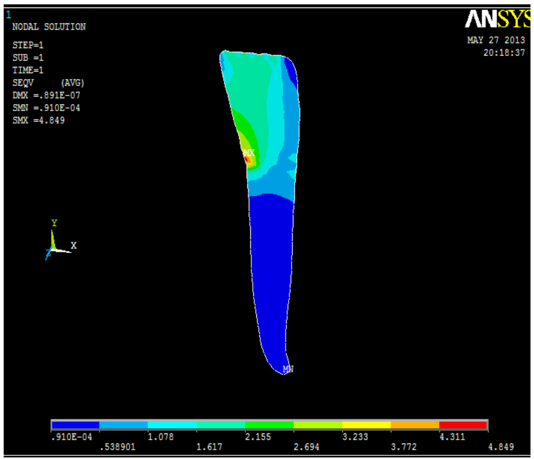

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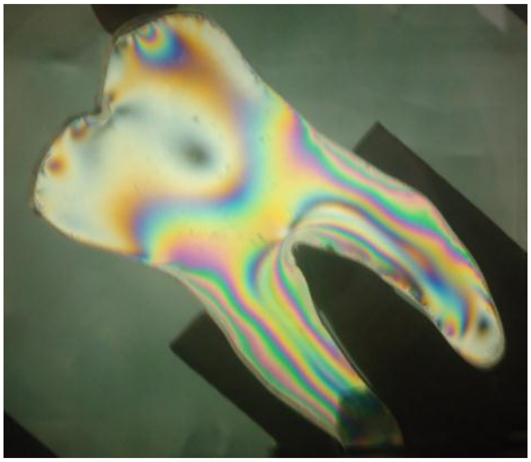
Fig. 6: Stress distribution pattern for mandibular molar, maxillary incisor and mandibular incisor respectivelty under vertical loading using a) photoelasticity b) finite element



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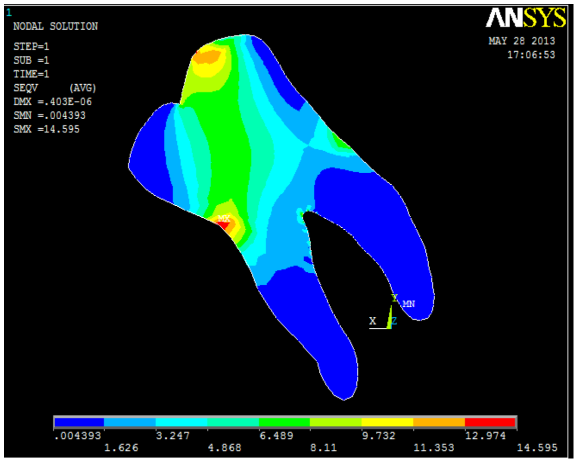

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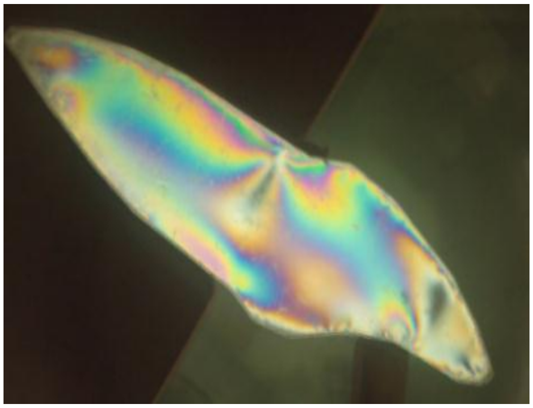

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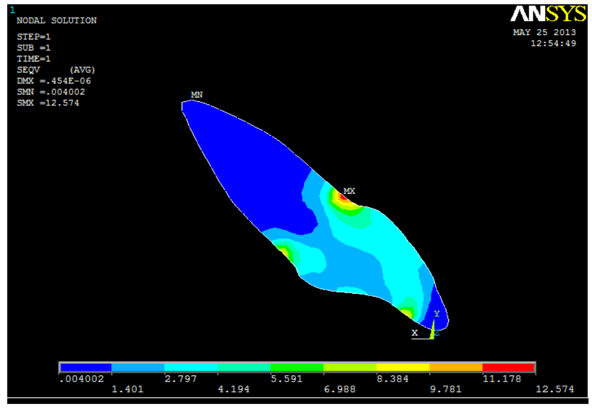

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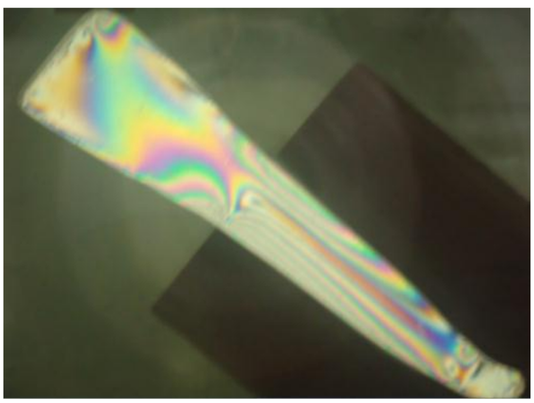

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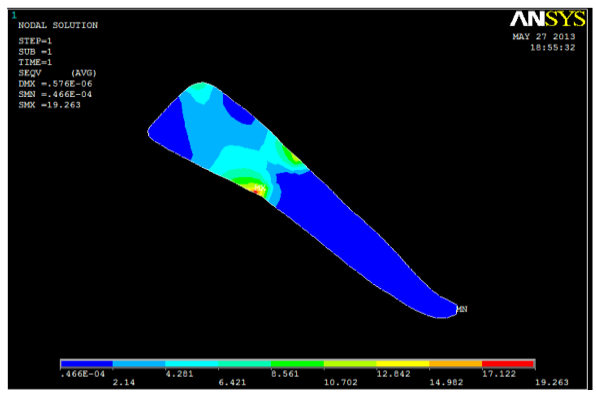

(b)

Fig. 6: Stress distribution pattern for mandibular molar, maxillary incisor and mandibular incisor respectivelty under oblique loading using a) photoelasticity b) finite element

Table 2. Deviation of the principles stresses (Mpa) determined by photoelastic analysis and by the finite elements method in three different regions of each tooth at vertical loading (55N).

Region	Mandibular First Molar			Maxillary Central Incisor			Mandibular Central incisor		
	PH	FE	ERROR%	PH	FE	ERROR%	PH	FE	ERROR%
Crown	2.720	2.730	0.361	5.440	5.500	1.000	3.400	3.213	-5.162
Cervical	3.400	3.510	3.133	2.720	2.882	5.621	4.040	4.391	5.510
Root	2.040	1.950	-4.615	2.040	2.315	14.357	3.400	3.233	-5.162

Table 3. Deviation of the principles stresses (Mpa) determined by photoelastic analysis and by the finite elements method in three different regions of each tooth at oblique loading (55N).

Region	Mandibular First Molar			Maxillary Central Incisor			Mandibular Central incisor		
	PH	FE	ERROR%	PH	FE	ERROR%	PH	FE	ERROR%
Crown	10.881	11.351	4.140	10.881	10.195	-5.931	13.550	13.642	0.674
Cervical	13.600	14.595	-6.817	11.081	11.469	3.391	16.232	17.122	-5.197
Root	8.160	7.229	-11.796	8.421	8.321	-1.201	8.160	8.601	5.127

5. CONCLUSIONS

Within the limitations of the present study, the results indicate the following:

1. The photoelastic approach provides a clear visual and qualitative picture of the stress distribution for the applied scientist, whereas the finite element approach provides a more detailed evaluation of the complete state of stress in the model for the researcher. The combination of the above methods permits a better understanding of the stress distribution in dental.

2. Maximum stresses generated by oblique loading were generally higher than the vertical loading.

3. Peak stresses were concentrated at the cervical in both mandibular first molar and mandibular central incisor, while at the crown in the maxillary central incisor.

4. The stress distribution obtained for a plane-stress by a photoelastic analysis is usually independent of the elastic constant. So that the magnitude of the stresses in real

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teeth different from those in a models. However, the location and general standard of these stresses are similar.

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