Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 9; April-June, 2015 pp. 77-81

http://www.krishisanskriti.org/jmsme.html

Structural and Thermal Analysis of Dental Restoration Materials using FEA Software

Salisu Umar Musa[1], Yusuf Abdulfatah Abdu[2] and Sunny Sharma[3]

[1,2,3]*Departmenof Mechanical and Automobile Engineering, Sharda University.*
E-mail: [1]assalis450@gmail.com, [2]abdulfatahabduyusuf@gmail.com, [3]sunny.sharma@sharda.ac.in

Abstract—*Little scientific information about dental restorative materials has been available until recently. Prior to this knowledge, the use of these materials was entirely an art, and the only tasting laboratory was the mouth of the patient. Today, despite the availability of the sophisticated technical equipment and development of standardized testing methods for evaluating the mechanical and thermal properties of restorative materials, this testing sometimes still occur on the mouth of our patients. The present work has considered and compared the essential mechanical and thermal properties of some of the most widely used restorative materials. The behaviour of these materials when used to filled class I cavity on mandibular first molar tooth, under the combinations of different thermal and structural loads were analysed using ANSYS (Work bench 15.0). Amalgam, Composite, and Gold alloys materials were considered for this work, the results obtained from ANSYS analysis showed that, the maximum deformation occurred at the occlusal surface, specifically on the filling material and increases towards the other four surfaces (mesial, buccal, lingual and distal surfaces) and the roots, while the equivalent (Von-Mises) stress was depicted along the cervical line (a border line between crown and roots) and distributed towards both the crown and the roots. 35 trials were made and the values for the maximum deformation and von-Mises stress were both plotted against the temperature andstructural load using Qtiplot software, and the final result showed that;Gold alloy and composite materials has the least andhighest values of both deformation and von-Mises stresses respectively.*

1. INTRODUCTION

The overriding goals of dentistry are to maintain or improve the quality of life of the dental patient. These goals can be accomplished by preventing diseases, relieving pain, improving mastication, enhancing speech and improving appearance.

Because many of these objectives require the replacement or alteration of the tooth structure, the main challenges for centuries have been the development and selection of biocompatible, long lasting, direct filling tooth restorative and indirect processed and prosthetic materials that can withstand the adverse condition of the oral environment.

Despite the public orientation by the body of domestic and international professionals, many people found it difficult or forgot to apply the normal health routine on their teeth. As a result, the part of the food which remained stuck to the person's teeth might generate bacteria which cause so many dental problems. For example, Tooth cavity *(a little hole which is formed when a sticky bacteria, called plaque, builds up on the teeth, slowly destroying the hard outer shell)*, is one of these disturbance diseases.

To treat a cavity the dentist will remove the decayed portion of the tooth and then "fill" the area on the tooth where the decayed material was removed. Fillings are also used to repair cracked or broken teeth and teeth that have been worn down from misuse (such as from nail-biting or tooth grinding). [9]

2. MATERIALS AND METHOD

After conducting several surveys from available literatures and different individual professionals, a mandibular first molar which was considered to experience the maximum biting force was selected. In addition, the mandibular first molar may be considered the most significant tooth, because of its early eruption; it may require restoration more frequently than any other tooth. [3]. "Usually, a mandibular first molar has five well-developed cusps: two buccal, two lingual, and one distal cusp. It has also two buccolingually broad roots, one in mesial and one in distal side, which are widely separated at the apices"[8]. A typical cross section of a tooth structure is shown in the Fig. below:

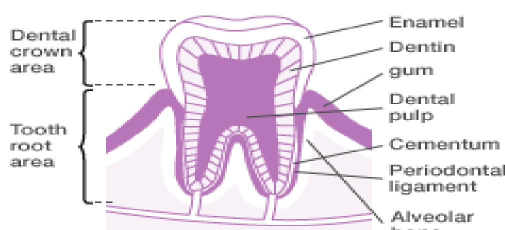

Fig. 2.1: Structure of the tooth

2.1 Software Approach

A major concern in clinical dentistry is the failure of the restored teeth. After undergone several dental treatments, the teeth might failed due to some certain inauspicious conditions.

This has encouraged some researchers to study mechanical and thermal response of the teeth after various dental treatments that are known to cause the dental failure. Consequently, the knowledge of stress and temperature distribution is essential. Moreover, the direct measurement of stress and temperature distributions across the buccal, mesial, lingual, distal and occlusal surfaces of the teeth is practically impossible because it is inaccessible.

A well-known method for determining the stress and temperature distribution within complex structure is the finite element method (FEM). The FEM has been proved to produce results similar to other experimental methods such as photoelastic and strain-gauge studies [3]. However, it is more comprehensive than the photoelastic technique, and it does not have the limitation of strain gauges, because it is not limited by fixture placement. In fact, the FEM provides more detailed and more controllable mechanical responses. [3].

2.2 Creating 3D model of Geometry

Generally, tooth geometry has a complex shape, thus; creating an accurate and true shape of the model is wearisome and time consuming. Therefore, an approximate model can be created by using available technologies and the method of Reverse Engineering. The extracted tooth which was reserved for clinical purposes was scanned using a Computer Tomography (CT) scan machine. The scanning takes place in different directions at different angles in order to obtain more accurate shape. The scanned image which was obtained as .DICOM file was converted to 3D model. It is also possible to create the 3D model by using a white light scanner. But creating the model using CT scan machine yields the most accurate result, because the point cloud data appeared as bunch of dots which is not as clear as DICOM file obtained from the CT scanning.

The file which was saved as .SLDPRT was opened using Solid Works software and a class I cavity was made on the model. Generally, a cavity made on a tooth is of several types, depending on the surface(s) it was made. Irrespective of the size or shape, when a cavity is made on the occlusal surface, it is called class I cavity, [1]. A filling material was then created which was used to fill the created cavity. The assembled model which was saved as.

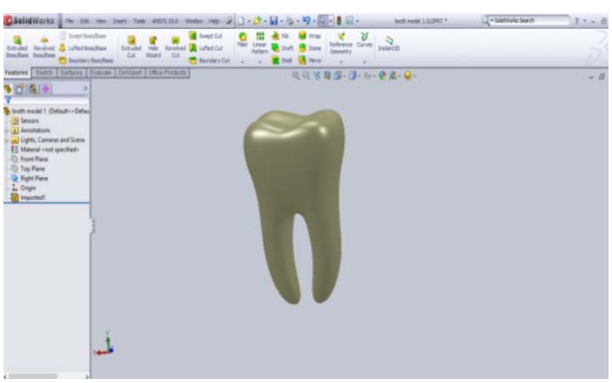

Fig. 2.2: 3D model of the geometry

IGES was transported to ANSYS Program for analysis. The model was meshed using fine size meshing for a better result and the materials properties were assigned. A typical tooth structure consists of an enamel, dentin, cementum and pulp tissue, as shown in Fig. 2.1 above. The portion of a tooth exposed to the oral cavity is known as the dental crown, and the portion below the dental crown is known as the tooth root. [13]Different combinations of the selected thermal and structural loads were considered, and the model was constrained to a desirable boundary condition.

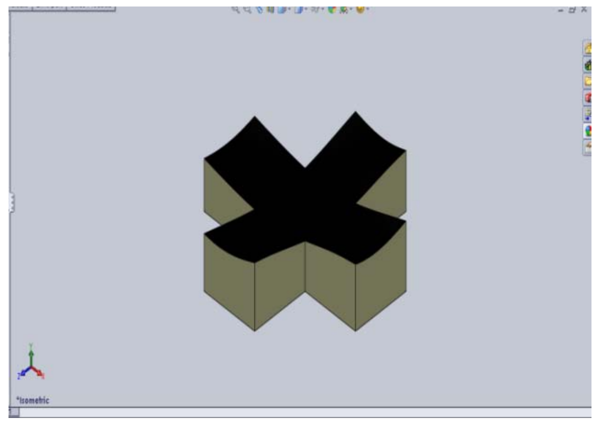

Fig. 2.3: Prepared filling material

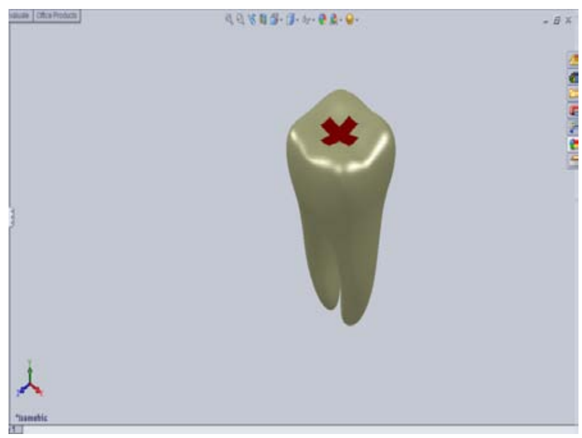

Fig. 2.4: Model filled with material

2.3 Design of Experiment

Three materials (Amalgam, Composites, and Gold alloy) were selected. For each material, combinations of both structural and thermal loading were considered. The maximum biting force decreases from the molar to the incisor region, and the average biting force on the first and second molar is about 580N [6]. Prior to this knowledge, four mastication forces, one above and three below the average was chosen. There has been limited published research accessing the range of oral temperatures that the hard and soft tissues are exposed to,but the temperature that tooth structure and dental restorations encountered might affect the performance of dental materials within the oral environment. “The maximum and minimum mouth temperatures recorded show that hot fluids can raise the intra-oral temperature of the front teeth to around 70 degrees Celsius and the consumption of iced drinks lowers the same teeth to around 0 degrees Celsius," [2]. For this purpose, four temperatures, ranges from of 0 to 60 degree Celsius at an interval of 20 degree Celsius was selected. Thus; a total of 48 numbers of experiments should be run (i.e. 3 materials, 4 structural forces and 4 temperatures).

3. RESULTS

For each combination of thermal and structural loading, the problem was solved and the resulting mechanical response was recorded. Some of the results are shown in the figure below**:**

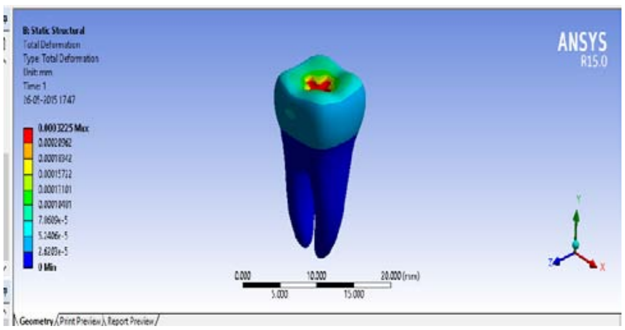

Fig. 3.1: Deformation analysis for Amalgam at 0 degree Celsius and 80N

Maximum deformation; 0.000323 mm

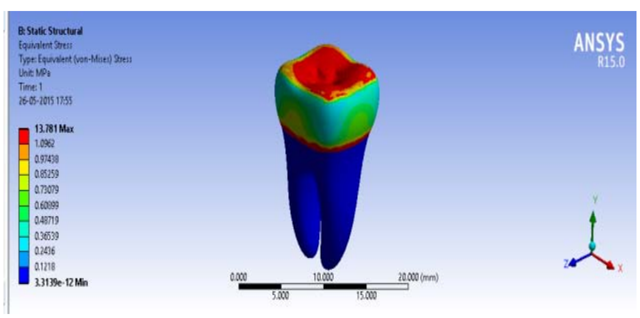

Fig. 3.2: Stress analysis for amalgam at 0 degree Celsius and 80N

Maximum Von- Mises stress; 13.781 N/mm^2

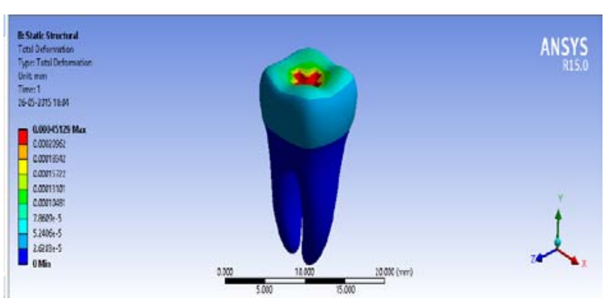

Fig. 3.3: Deformation analysis for Composite at 0 degree Celsius and 80N

Maximum Deformation; 0.0004513 mm

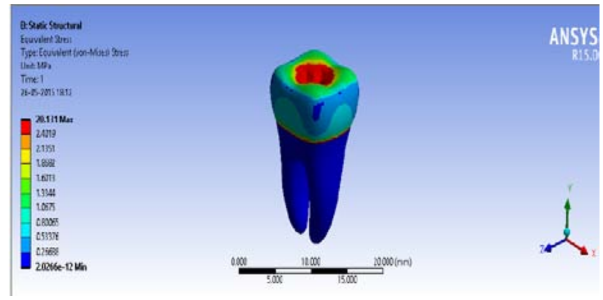

Fig. 3.4: Stress analysis for composite at 0 degree Celsius and 80N

Max. Von- Mises stress; 20.131N/mm^2

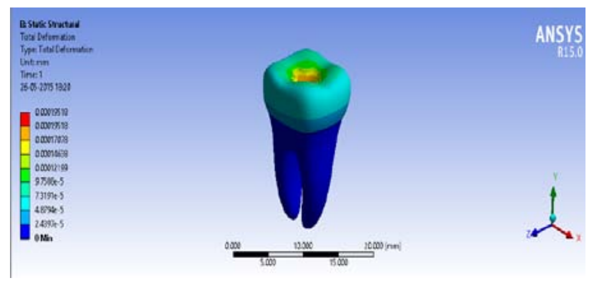

Fig. 3.5: Deformation analysis for Gold alloy at 0 degree Celsius and 80N

Max. Deformation; 0.0001952

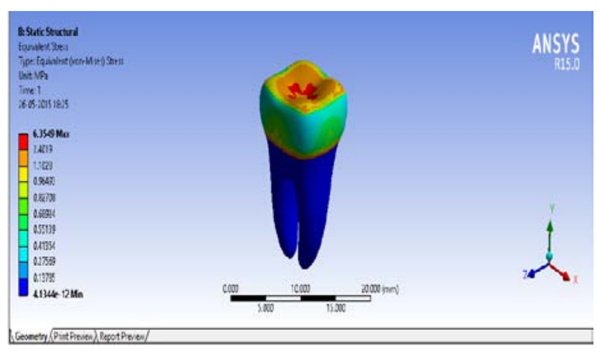

Fig. 3.6: Stress analysis for Gold alloy at 0 degree Celsius and 80N

Max. Von- Mises stress; 6.355N/mm^2

The mechanical responses (maximum deformation and Von-Mises stress) for all trials was plotted against both temperature and load for each material using Qtiplot for a 3D visualization, and the resulting 3D surfaces is shown in the figure below.

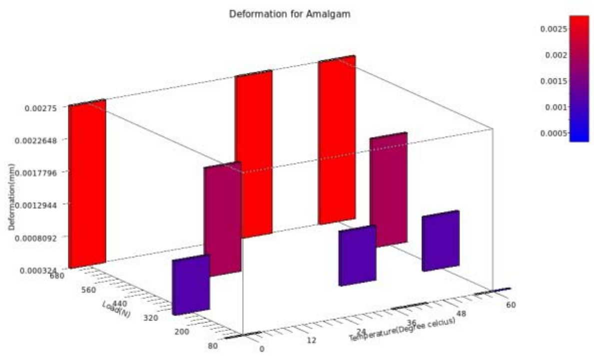

Fig. 3.7: 3D graph of Amalgam deformation

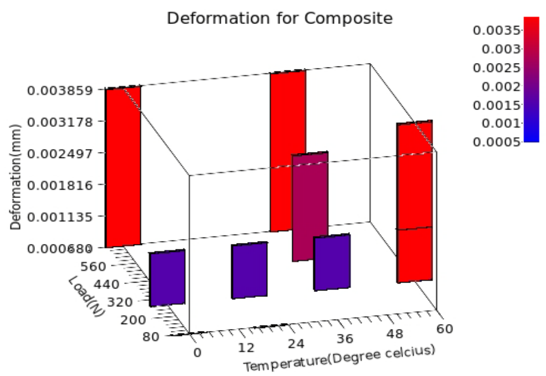

Fig. 3.8: 3D graph Composite deformation

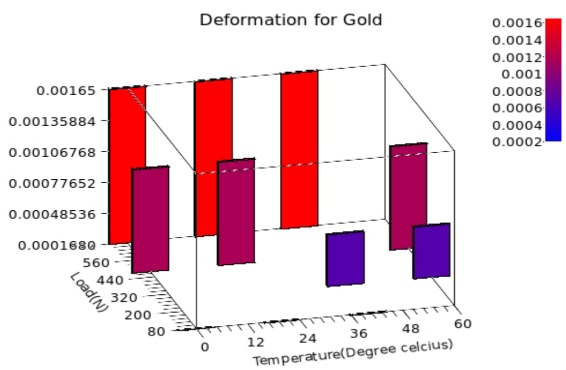

Fig. 3.9: 3D graph of Gold alloy deformation

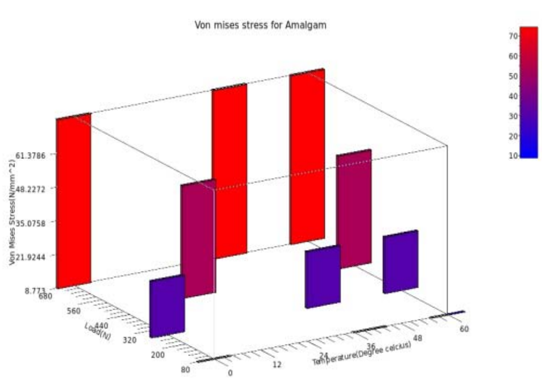

Fig. 3.10: 3D graph of Amalgam (Von-Misses) stress

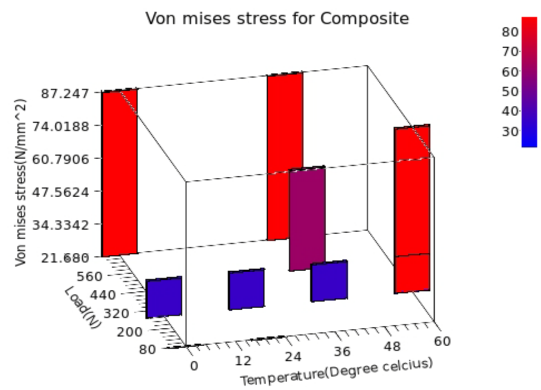

Fig. 3.11: 3D graph of Von-Mises stress for Composite

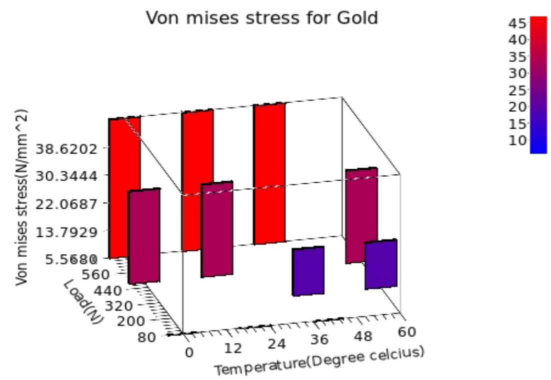

Fig. 3.12: 3D graph of Von –Mises stress for Gold ally

4. CONCLUSION AND DISCUSSION

The results obtained from ANSYS analysis above showed that, the maximum deformation occurred at the occlusal surface, specifically on the filling material and increases towards the other four surfaces (mesial, buccal, lingual and distal surfaces) and the roots, while the equivalent (Von-Mises) stress was depicted along the cervical line (a border line between crown and roots) and distributed towardsboth the crown and the roots.

The result also shows that, the increase in the deformation and stress concentration values was contributed by the increase in the structural loads but independent of the thermal loads (temperature between 0 to 60^0C) used in this work. The non-variation of the result with respect to temperature might be due to the fact that; the of temperature range considered (0 to 60^0C), is much- much less than the melting temperature of all the material used as the filling material.

It is also clear that; the properties of all engineering materials are varied with varying temperature, hence in this work, the properties at room temperature for all the selected materials were considered for all set of temperature ranges used in this work.

Further analysis of the result by using a Qtiplot 3D surface graph shows that; Gold alloy has the leastdeformation values, while the maximum deformation was recorded when composites material was used. Moreover, Gold alloys and composites materials have the minimum and maximum (von-Mises) stresses respectively.This can be due to the fact that, gold alloy has a close proximity with human Enamel and Dentin in its mechanical properties.

5. ACKNOWLEDGEMENT

It is the authors' privilege to recommend the remarkable effort made by the following group and individual professionals for the successful completion of this work.

1. Dr Ekta Choury, (professor, HOD), Department of conservative dentistry and Endodontic, Sharda University, Greater Noida.
2. Sharda University Hospital, Greater Noida.
3. Lelogix CAD Training Centre, Alpha I, Greater Noida.

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