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Finite Element Analysis for Molar-Tooth Treatment with Different Filler Merials

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ملخص البحث

عادة ما ينتج تسوس الأسنان من الأحماض التي تنتجها البكتريا الناتجة من التفاعل الغذائي، والتي تؤدي في النهاية الى تجاويف. وتتطور هذه التجاويف تتطور إلى فتحات صغيرة، أو حفر في أعماق السن. وهي نوع شائع يتسبب في أمراض الأسنان، حيث أنها تحدث عادة على سطح السن أو التاج. وعادة ما يتعامل أطباء الأسنان مع هذه الحالات بتنظيف التسوس وعمل تجويف مناسب والاستعاضة عنها بحشوات خاصة.

وهذا البحث دراسة وتحليل لعدد من الحشوات المختلفة المستخدمة في علاج تسوس الأسنان (الضرس). وقد استخدمت نظرية العناصر المحدودة باستخدام برنامج إي-إن-إس-واي-إس (ANSYS) في هذه الدراسة، والتي يتم فيها تحليل الإجهادات على الأسنان مع حشوات مختلفة، وهي: الأملغم، والذهب، والمواد المركبة التي تستخدم في الحشوات في العيادات، ومقارنتها بالسن العادي من دون حشوة أو تجويف. وتشير الدراسة إلى أن الأملغم هو الأقرب في النتائج إلى السن العادي من دون حشوة.

ABSTRACT.

Dental caries grows by the localized dissolution of the tooth hard tissues, caused by acids that are produced by bacteria in the dental plaque on the teeth and eventually lead to "cavities". These cavities are decayed areas of the tooth that develop into tiny openings or holes, a pit and fissure cavities are the common type of tooth diseases which occurs on the chewing surface of the teeth. Dentists treated the tooth by removing the decayed tooth material with a drill and replacing it with a filler material.

This study is an investigation of the molar tooth treatment with different filler materials, amalgam, composites and gold. The analysis is completed and achieved by using finite element analysis with ANSYS software. Therefore, the results are indicating that the amalgam is the best filler material for molar tooth treatment.

Keywords:
Finite Element Analysis, Dental Analysis, Filler Material, Tooth Treatment.

1. Introduction:

Dental caries (tooth decay) is probably the most common regular diseases in the world. Although caries has affected humans since antiquity, the popularity of this disease has greatly increased worldwide now owing to food changes. Tooth decay usually occurs in children and young adults but can affect any person. The bacteria are normally present in the mouth. These bacteria convert all foods (especially sugar and starch) into acids. Furthermore, these bacteria, acid, food debris, and saliva combine in the mouth to form a sticky substance called plaque that adheres to the teeth (see Figure 1 and 2). It is most prominent on the back molars, just above the gum line on all teeth, and at the edges of fillings. Plaque that is not removed from the teeth mineralizes into tartar. Plaque and tartar irritate the gums. Plaque begins to build up on teeth within 20 minutes after eating (the time when most bacterial activity occurs). If this plaque is not removed thoroughly and routinely, tooth decay will not only begin, but also grow [1, 2, 3, 4].

The acids in plaque dissolve the enamel surface of the tooth and create holes in the tooth (cavities). Cavities are usually painless until they grow very large and affect nerves or cause a tooth fracture. If left untreated, a tooth abscess can develop. It also destroys the internal structures of the tooth (pulp) and ultimately causes the loss of the tooth [5, 6, 7].

However, there are three types of cavities. Smooth surface cavities occur on the smooth sides of the teeth, while root cavities develop on the surface over the roots. Hollow and crack cavities occur on the chewing surface of the teeth, as shown in Figure 3 & 4.

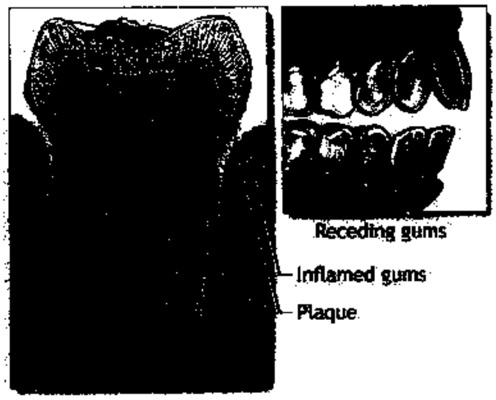


Figure 1: Plaque that adheres to the teeth

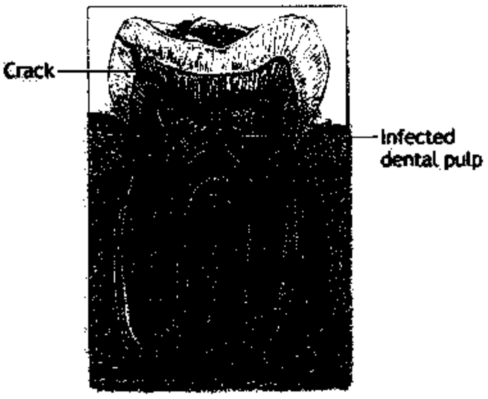


Figure 2: Infected dental pulp

Figure 3: Hollow and crack cavities

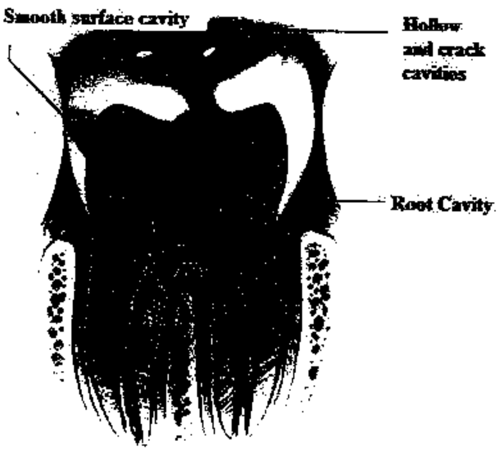


Figure 4: Types of tooth cavities

Tooth treatment can help to avoid the tooth damages from leading to cavities. Fillings, crowns and root canal are the most common type of tooth treatments. Dentists fill teeth by removing the decayed tooth material with a drill and replacing it with a material such as gold, silver amalgam alloy, or composite resin. Composite resin more closely matches the natural tooth appearance, and may be preferred for front teeth. Many dentists consider silver amalgam (alloy) and gold to be stronger, and these materials are often used on back teeth. There is a trend to use high strength composite resin in the back teeth as well [8, 9].

Crowns, or "caps" are used if tooth decay is extensive and there is limited tooth structure, which may weaken teeth. Large fillings and weak teeth increase the risk of the tooth breaking. The decayed, or weakened area is removed and repaired. A crown is fitted over the remainder of the tooth. Crowns are often made of gold, porcelain, or porcelain attached to metal [10, 11].

A root canal is recommended if the nerve in a tooth dies from decay or injury. The center of the tooth, including the nerve and blood vessel tissue (pulp), is removed along with decayed portions of the tooth. The roots are filled with a sealing material. The tooth is filled, and a crown may be placed over the tooth if needed, Figure 5 shows tooth structure includes dentin, pulp and other tissues, blood vessels and nerves imbedded in the bony jaw [12].

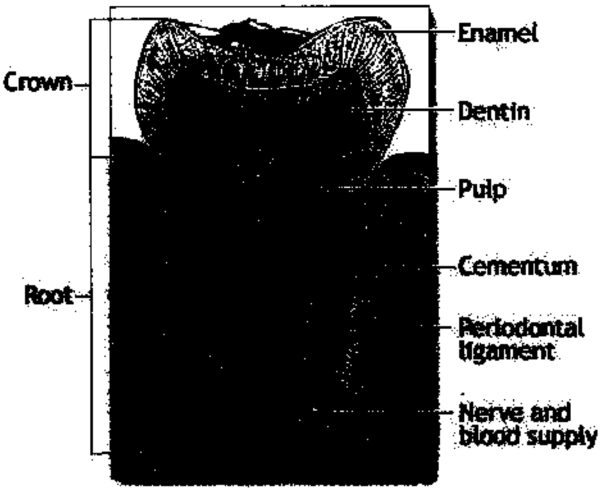


Figure 5: Tooth anatomy

However, many studies on filler composition and polymerization methodology for composite materials have resulted in both increased esthetic qualities and resistance to wear. Similarly, the benefits of sealants are becoming more widely accepted for the prevention of hollow -and-fissure caries.

Further research on biomaterials has led to the introduction of vastly improved dental materials. Developments in impression materials and gold foil and advancements in knowledge about liners and sealers are also factors that have resulted in better care and treatment for patients. Advances in metallurgy have resulted in a variety of improved alloys that are either already available, or are being developed. Corrosion-resistant amalgam alloys have been developed, which will enhance the oral health of the population by providing longer lasting restorations [12,13].

2. Filler Materials:

In this study, there are three different filler materials used for molar tooth treatment: dental amalgam, gold and composites [14:18]:

2.1. Dental Amalgam

Amalgam technically means an alloy of mercury (Hg) with any other metal. Dental amalgam is an alloy made by mixing mercury with a silver-tin dental amalgam alloy (Ag-Sn), see Table 1.

2.2. Direct-Filling Gold

Gold is extremely soft and may be welded to itself under pressure at room temperature if the surfaces being fixed and cleaned. This makes gold applicant to a direct restoration. Although it has been used this way for more than a century, the process is tedious, difficult, and relatively expensive for the patient.

Gold for direct-filling restorations may be classified on the basis of (1) the geometric form in which it is supplied; (2) the surface condition of the part; and (3) the microstructure of the part. It may be supplied as ropes, sheets, strips, or pellets. Direct gold is essentially 100% gold. Pre-alloying with other elements would reduce the weldability and malleability at room temperature. However, other elements may incorporate (platinum or calcium) indirectly into the final structure by layering them onto the gold in form such as gold foils. During cold welding, much greater compaction pressures are required to remove pores or spaces in mat gold and powdered gold than in gold foil.

2.3. Composites

A composite is a physical mixture of materials. The parts of the mixture are generally chosen with the purpose of averaging the properties of the parts to achieve intermediate properties. Quite often, a single material does not have the appropriate properties for a specific dental application. Composites typically involve a dispersed phase of filler particles distributed within a continuous phase (matrix phase). In most cases, the matrix phase is fluid at some point during the manufacture or fabrication of a composite system. A dental composite has traditionally indicated a mixture of silicate glass particles within an acrylic monomer polymerized during the application. The silicate particles provide mechanical reinforcement of the mixture (reinforcing fillers) and produce light transmission and light scattering that adds enamel like transparency to the material. The acrylic monomers make the initial mixture fluid and moldable for placement into a tooth preparation. The matrix flows to adapt to tooth preparation walls and penetrate into micromechanical spaces on etched enamel or dentin surfaces.

3. Background of Molar Tooth Analysis Using FEM:

Several studies for tooth analysis using FE method such as *(Genovese, et al, 2004)* [19] investigated the mechanical behavior of a new customized post system built up with a composite framework presently utilized for crowns, bridges, veneers and mainly only dental restorations. The material has been shaped so as to follow perfectly the profile of the root canal in order to take advantage of the better mechanical properties of composites with respect to metallic alloys commonly used for cast posts. The analysis has been carried out with 3-D finite element models previously validated on the basis of experimental work. The new post system has been compared to a variety of restorations using either prefabricated or cast posts. The structural efficiency of the new restoration has been evaluated for an upper incisor under different loading conditions (mastication, bruxism, impact).

Results prove that maximum stress values in restored teeth are rather insensitive to post types and materials. However, the new customized composite restoration allows to reduce significantly the stresses inside the dentinal regions where conservative clinical interventions are not possible.

Pattijn, et al, (2005) [20] evaluated the modal behavior of the bone–implant–transducer (Osstell) system by means of finite element analyses. The influence of different parameters was determined: (1) the type of implant anchorage being trabecular, cortical, uni-cortical, or bi-cortical; (2) the implant diameter; (3) the length of the implant embedded in the bone; and (4) the bone stiffness.

The type of anchorage determines the resulting modal behavior of the implant–transducer system. A rigid body behavior was found for a uni-cortical anchoring and homogeneous anchoring with low bone stiffness (≤1000 MPa), whereas a bending behavior was found for a homogeneous anchoring with a high bone stiffness (≥5000 MPa) and bi-cortical anchorage. The implant dimensions influence the values for the resonance frequencies. Generally, an increase in implant diameter or implant length (in bone) results in higher resonance frequencies. Their study also showed that resonance frequencies in case of rigid body behavior of the implant–transducer system are more sensitive to changes in bone stiffness than resonance frequencies in case of bending behavior. In conclusion, it seems that the Osstell transducer is suited for the follow-up in time of the stability of an implant, but not for the quantitative comparison of the stability of implants [20].

DeHoff, et al, (2004) [21] studied the viscoelastic option of the ANSYS finite element program to calculate residual stresses in an all-ceramic FPD for four ceramic–ceramic combinations. A three-dimensional finite element model of the FPD was constructed from digitized scanning data and calculations were performed for four systems: (1) IPS Empress 2, a glass-veneering material, and Empress 2 core ceramic; (2) IPS ErisTM a low fusing fluorapatite-containing glass-veneering ceramic, and Empress 2 core ceramic; (3) IPS Empress 2 veneer and an experimental lithium–disilicate-based core ceramic; and (4) IPS ErisTM and an experimental lithium–disilicate-based core ceramic. The maximum residual tensile stresses in the veneer layer for these combinations were as follows: (1) 77MPa, (2) 108MPa, (3) 79 MPa, and (4) 100MPa. These stresses are relatively high compared to the flexural strengths of these materials. In all cases, the maximum residual tensile stresses in the core frameworks were well below the flexural strengths of these material. They concluded that the high residual tensile stresses in all-ceramic FPDs with a layering ceramic may place these systems in jeopardy of failure under occlusal loading in the oral cavity [22].

Ueda, et al, (2004) [23] investigation used the comparison of photoelastic analysis, the stress distribution in a fixed prosthesis with 3 parallel implants, to the stress distribution in the same prosthesis in the existence of an angled central implant. Two photoelastic resin models were made and a polariscope was used in the visualization of isochromatic fringes formed in the models when axial loads of 2 kg, 5 kg and 10 kg were applied to a unique central point of the prosthesis. The presence of inducted tensions (preloads) was observed in the models after applying torque to the retention screws. Preloads were intensified with the incidence of occlusal forces. In the parallel implants, the force dissipation followed the long axis. The angled implant had a smaller quantity of fringes and the stresses were located mostly around the apical region of the lateral implants.

A 3-D solid model of a human maxillary premolar was prepared and exported into a 3-D-finite element model (FEM) by *Ausiello, et al,* (2001) [24] and a generic class II MOD cavity preparation and restoration was simulated in the FEM model by a proper choice of the mesh volumes. A validation procedure of the FEM model was executed based on a comparison of theoretical calculations and experimental data. Different rigidities were assigned to the adhesive system and restorative materials. Two different stress conditions were simulated: (a) stresses arising from the polymerization shrinkage and (b) stresses resulting from shrinkage stress in combination with vertical occlusal loading. Three different cases were analyzed: a sound tooth, a tooth with a class II MOD cavity, adhesively restored with a high (25GPa) and one with a low (12.5 GPa) elastic modulus composite.

The cusp movements induced by polymerization stress and (over)-functional occlusal loading were evaluated. While cusp displacement was higher for the more rigid composites due to the prestressing from polymerization shrinkage, cusp movements turned out to be lower for the more flexible composites in case the restored tooth which was stressed by the occlusal loading.

This preliminary study by 3-D FEA on adhesively restored teeth with a class II MOD cavity indicated that Young's modulus values of the restorative materials play an essential role in the success of the restoration. Premature failure due to stresses arising from polymerization shrinkage and occlusal loading can be prevented by proper selection and combination of materials [25].

Ghulman and Al-Hazmi (2008) [26] investigated the stress analysis of the molar tooth under loading conditions with different angles, using finite element package ANSYS. The results of their study indicated that the maximum shearing stress and deformation ~~is~~ increases with decreasing directional angle of the applied load.

The objective of this study is to investigate the stresses and deformations in proximal dentine of human molar-tooth with different filler materials. A finite element model of molar-tooth was constructed, based on a 3-D solid modeling using AutoCAD and exported to ANSYS FE software to calculate the stress deformation distributions on the molar tooth with different filler materials which are implemented in a cavity, located in the middle of the tooth crown.

4. Finite Element Modeling for Molar-Tooth

The approach in this study is to model the molar-tooth by using the 3D finite element modelling capabilities of ANSYS with cavity located in the central part of the tooth crown. In this FE analysis, different filler materials are added to the tooth cavity.

4.1. Molar-tooth Geometrical Model and Boundary Conditions:

Two steps were used for modeling the molar-tooth. First, a 3-D solid modeling is constructed using AutoCAD with a cavity at the top center of the tooth crown, as shown in Figure 6. Subsequently the model is exported to ANSYS for FE Analysis.

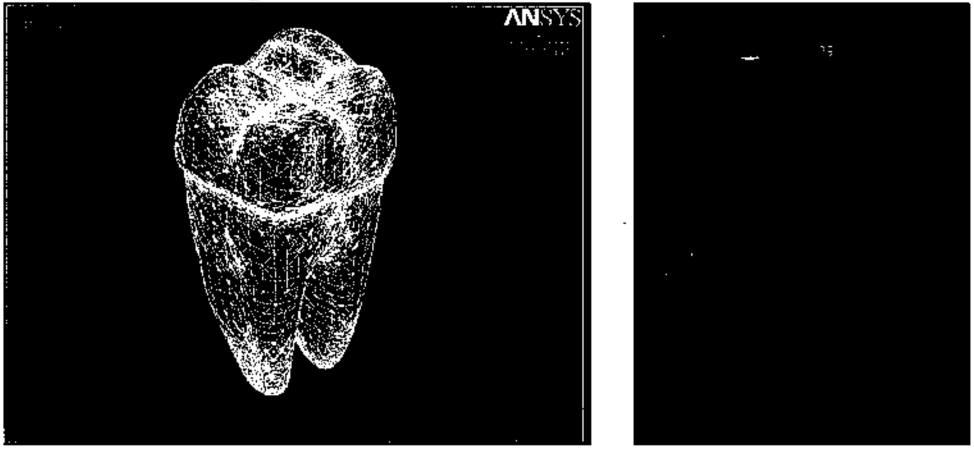
Figure 7 (a&b) shows the molar-tooth modelling by ANSYS. The 3-D element SOLID92 with 6 degree of freedom is used for modelling the molar-tooth. The molar-tooth geometry was meshed to 423693 elements as shown in Figure 7(a).

The boundary conditions of the molar-tooth are:

Displacements in all three directions of the coordinate axes are zero at the roots of the tooth, as illustrated in Figure 8: $U_x = U_y = U_z = 0$.

Also rotations about all three coordinate axes are zero at the roots of the tooth, as shown in Figure 8: $Rot_x = Rot_y = Rot_z = 0$.

Figure 6: 3-D soled model of molar-tooth



a: 3-D finite element meshed molar-tooth model b: 3-D molar tooth with filling material

Figure 7: 3-D Finite element modelling of molar-tooth with filler material

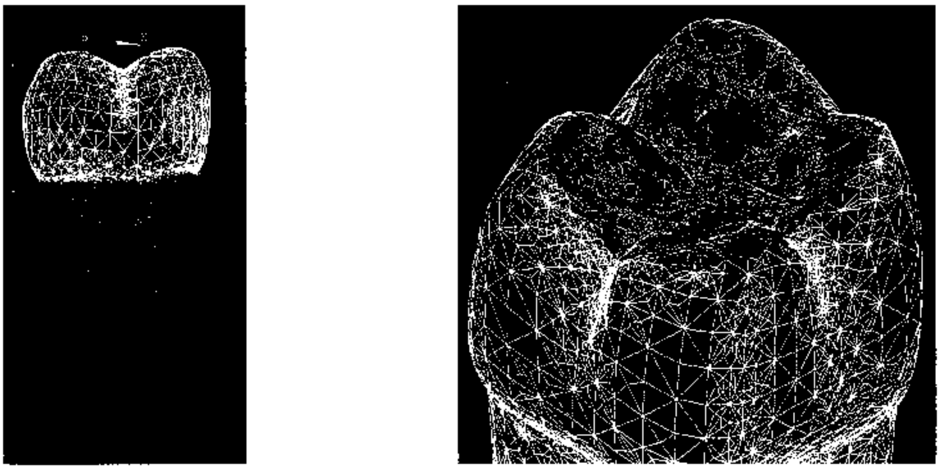


Figure 8: Boundary conditions for molar-tooth

4.2. Physical Properties

Table 1 gives the physical properties for the different materials:

Table 1: Material properties [*Genovese, et al (2004), and Lee, et al, (2002)*]

Material	Yield modulus E (MPa)	Possion ratio's v
Enamel	84100	0.20
Dentine	18600	0.31
Pulp	2	0.45
Amalgam	27600	0.35
Gold (alloy)	99300	0.3
Composite alloy	218000	0.35

5. Results and Discussion:

The results are presented for, molar-tooth cavity treated with three different filler materials (Amalgam alloy, composites, and gold) applied pressure over the top surface of molar tooth crown with 100 N/mm^2.

Molar- tooth without cavity (natural tooth):

Figure 9 (a & b) shows the finite element results of the molar-tooth deformation and maximum shear stress profiles. The results show that the maximum deformation is 0.362967 mm at the top surface of the molar tooth and maximum shear stress is 7590. MPa at the top surface of the molar-tooth.

Molar-tooth with Amalgam filler material:

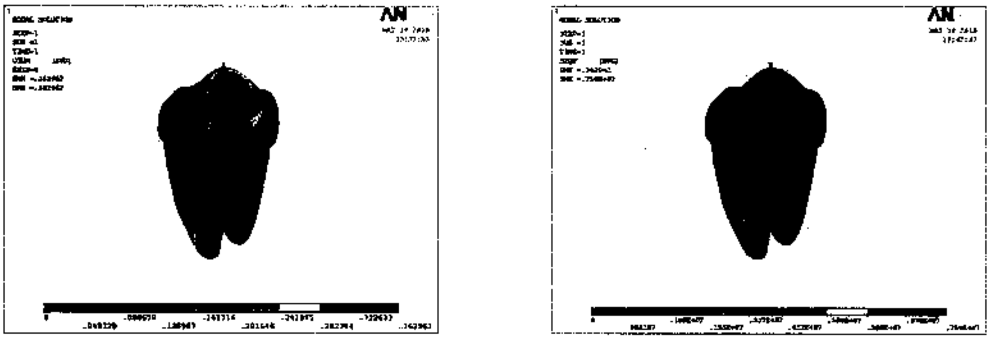
Figure 10 a & b shows the finite element results of the molar-tooth with cavity treated by amalgam filler material. The results show that the maximum deformation is 0.352621 mm at the top surface of the tooth and maximum shear stress is 7510 MPa at the top surface of the tooth. The results indicate that the total deformation of the molar-tooth with filler of amalgam material is less than the total deformation of the molar-tooth without filler, and the maximum shear stress of on the molar-tooth with filler of amalgam material is less than the molar-tooth without cavity at similar conditions.

Molar-tooth with gold filler material:

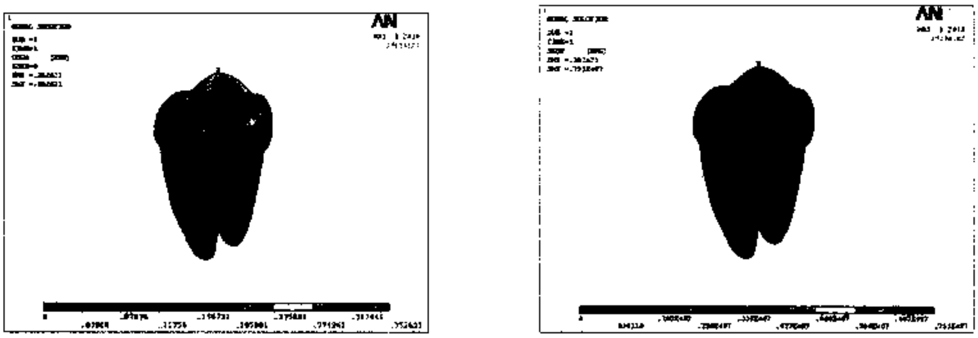
Figure 11 a & b shows the finite element results of the molar-tooth with a cavity treated by gold filler material. The results show that the maximum deformation is 0.325829 mm at the top surface of the tooth and maximum shear stress is 7270 MPa at the top surface of the tooth. The results indicate that the total deformation of the molar-tooth with a filler of gold material is less than the total deformation of the tooth with a filler of amalgam material, and the maximum shear stress on the molar tooth with a filler of gold material is less than the molar-tooth with a filler of amalgam material at similar conditions.

Molar-tooth with composite filler material:

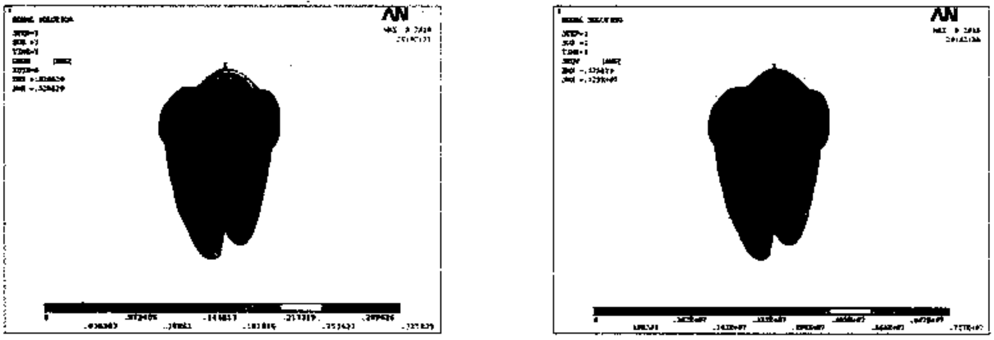
Figure 12 a & b shows the finite element results of the molar-tooth with a cavity treated by composite filler material. The results show that the maximum deformation is 0.315388 mm at the top surface of the tooth and maximum shear stress is 7225 MPa at the top surface of the molar-tooth. The results indicate that the total deformation of the molar-tooth with composite filler material is less than the total deformation of the tooth with a filler of gold and amalgam material, and the maximum shear stress of on the molar tooth with filler of composite material is less than the molar tooth with a filler of gold and amalgam material at similar conditions.



(a) Total deformation of the molar tooth(b) Von Mises stress of the molar tooth
Figure 9: A finite element results for molar-tooth without cavity

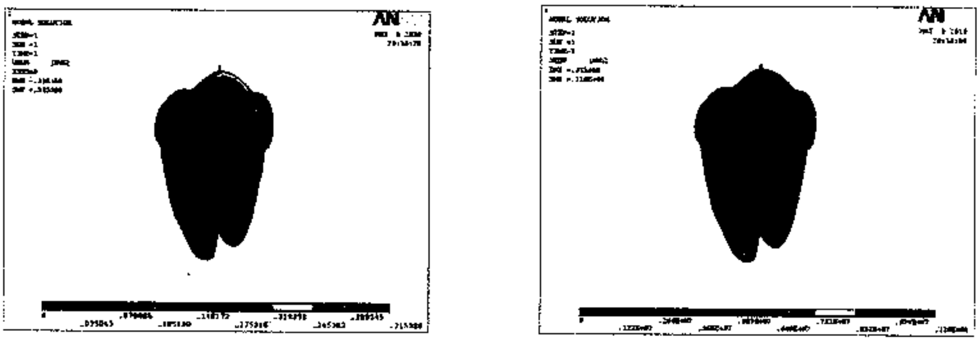


(a) Total deformation of the molar tooth(b) Von Mises stress of the molar tooth
Figure 10: A finite element results for molar-tooth with amalgam filler material



(a) Total deformation of the molar tooth(b) Von Mises stress of the molar tooth

Figure 11: A finite element results for molar-tooth with gold filler material



(a) Total deformation of the molar tooth(b) Von Mises stress of the molar tooth
Figure 12: A finite element results for molar-tooth with composite filler material

5. Comparison between the molar tooth and filler materials:

Figures 13, 14, 15 and 16 show a graphical evaluation of molar-tooth without a cavity, and with a cavity filled with different filler materials (amalgam, gold, and composite) alongside the molar-tooth and cross over the crown part of the molar tooth. The results indicate that the total deformation across the molar tooth is higher at molar tooth without a cavity than the tooth with filler material. As that it, increases with amalgam to gold and it decreases with composite to gold as shown at Figure 13. Furthermore, the maximum shear stress is almost similar at molar tooth without a cavity as molar tooth with amalgam filler material. However, the maximum shear stress is not quite less than the tooth with amalgam filler material as the filler with gold and composite materials, as shown in Figure 14.

Figure 15 shows the total deformation along the molar tooth. The results indicate that the total deformation at the crown part of the molar tooth is higher than the tooth with filler material. Besides that, it increases more with amalgam than gold, and decreases more with composite than gold. On the other hand, the von Mises stress (Figure 16) is the lowest at molar tooth without cavity than molar tooth with filler materials. In addition, the von Mises stress increases with filler treatment, whereas the molar tooth with composite filler is higher than the molar tooth with amalgam and gold.

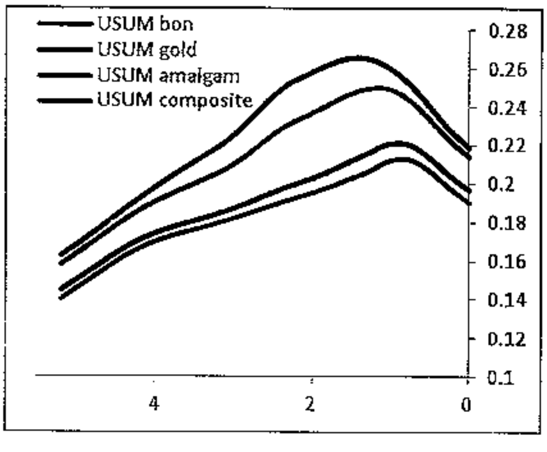


Figure 13: Total deformation of molar tooth relations across the crown

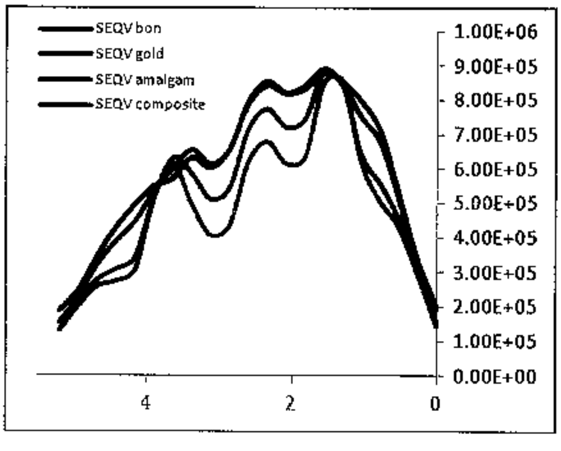


Figure 14: von Mises stress of molar tooth relations across the crown

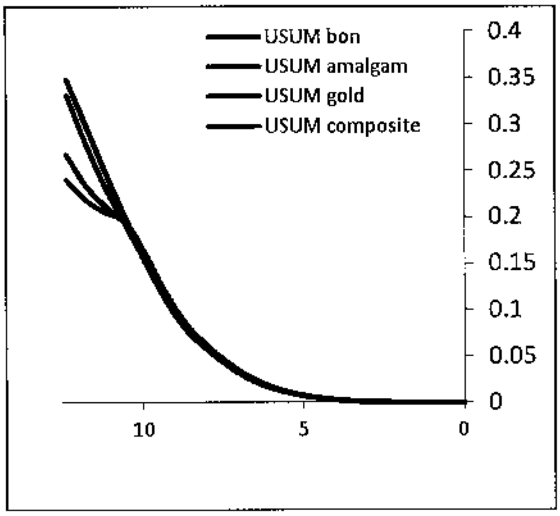


Figure 15: Total deformation of molar tooth relations along the molar tooth

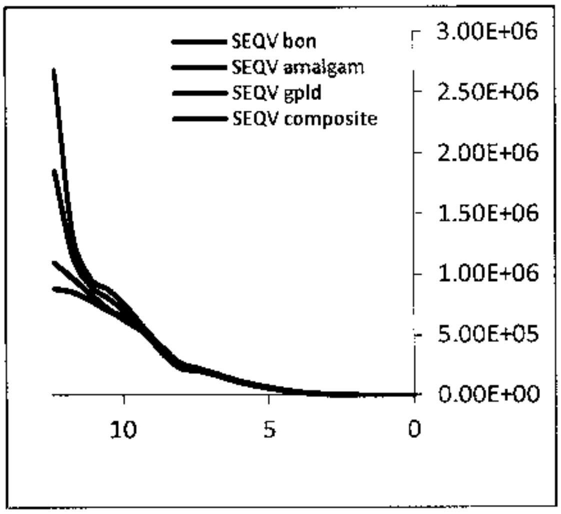


Figure 16: Von Mises stress of molar tooth relations along the molar tooth

6. Conclusion and Recommendations

This study presents a finite element analysis of the molar-tooth cavity treated with different filler materials to identify the stresses and deformations.

The results are represented in terms of maximum shear stress and total deformation for the molar tooth cavity treated with three types of filler materials (amalgam, gold, and composite). The results indicate that the maximum shear stress is the lowest with composite filler material, and increases with gold filler, amalgam filler and without cavity respectively. The total deformation is the lowest with composite filler. However, the total deformation increases with gold filler, amalgam filler, and the tooth without cavity respectively. Thus, the filler treatment with amalgam material is closer to that for the normal molar tooth without cavity. Therefore, the amalgam filler material is approximately more appropriate filler material than the gold and composite filler materials.

6.1. Recommendation for Future Work

There are several areas where more work is needed for analysis of molar-tooth. Among these studies are:

1- The study of another type of tooth treatment such as root canal tooth treatments.
2. Finite element analysis of tooth implementation.
3- The study and evaluation of molar-tooth treatment with different filler materials in order of thermal variation.

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