Numerical and Experimental Analysis to Predict Life of Removable Partial Denture

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Abstract. Specialist has attempted to treat or replace teeth in case of human dental damage as a result of illness or misuse at certain stages of life. Alternating force affects the life of teeth, and this force causes failure. In this study, partial molar denture was manufactured from a composite material, including polymethylmethacrylate acrylic with zirconia, at different weight fractions (0, 2.5, 5 and 7.5 wt%). Mechanical tests (compression and hardness) were conducted for these samples, and the best weight fraction was selected to manufacture the partial molar denture. The chewing force was measured using a F-sensor. Numerical solution was achieved using the solid work software to determine the best sample and study the distribution of the dental stresses. To predict the life of the denture experimentally, we designed and manufactured a new device that can determine the life of the dental by applying alternative load which simulates the force generated by chewing.

Keywords: PMMA, Zirconia, Fatigue tester, F-sensor, Partial dentures.

1. Introduction
Dentures are prosthetic devices constructed to replace damaged teeth. Conventional dentures are removable (partial or complete dentures). Removable dentures have many functions, such as biting, chewing and grinding food. Teeth primarily affect the function of speaking, aesthetics and protection of soft tissue. Each tooth consists of a crown, roots and a neck which stretches between the crown and the root. The tooth has four basic tissues, such as enamel, dentin, cemented tissues and pulp tissues. The crown is made up of enamel, dentin and pulp tissues. The root is made up of cemented and pulp tissues. Several pathological factors, traumas and tooth lesions can cause partial or complete tooth loss. Modern dentures are most often fabricated in a commercial dental laboratory or by a dentist by using a combination of tissue-shaded powder polymethylmethacrylate acrylic (PMMA). These acrylics are available as heat- or cold-cured types. Many researchers have studied the load distribution on the dental surface. Mahler and Peyton studied photelasticity as a research technique in analysing...
stresses in dental structures. The photo-elastic method and its application to dental restorative design evaluates the maximum stresses. Pedersen et al. analysed the displacement of tooth on human autopsy material via the strain gauge technique on the sections of the mandible, including the first molar. Nakamura et al. analysed the photo-elastic stress of mandibular molars moved distally with the skeletal anchorage system. Two types of photoelastic mandibular dentition models were used. Another study by Musani et al. included a biomechanical stress analysis of the mandibular first permanent molar restored with amalgam and composite resin by using a computerised finite element study. This study aimed to analyse the effect of repeated load due to the mastication of food on modern molar dentures made by using a combination of tissue-shaded powder PMMA. Where, multi researchers investigation the removable partial denture with various parameters and technique as presenting, At, 2005, L. Ardelean et. al., [1], presented numerical analysis by using finite element technique to calculate the stress distribution in teeth with removable denture. Where, the investigation included calculate the maximum stresses and equivalent stress of teeth. After this, at 2012, O. Ozan et. al., [2], investigated the alveolar bone resorption with effect of removable partial dentures. Where, the investigation included development of 3-D representations by the CBCT scans, and calculated the distance for mandible for different Kennedy regions. Then, at 2015, A. B. El-Okl, [3], investigated for different design support and calculate the stresses distribution with effect for its supports. Where, the study included using finite element technique to calculate the results require. In addition to, the investigation included calculated for von Mises and stress concentration for model used at loaded area. Then, the results shown that the stress concentration decrease at abutment for pier with using of design of removable partial over-denture. After this, at 2019, X. Chen, [4], studied for various denture design with different materials framework by using 3-D finite element technique. Where, the investigation included calculated for stress distribution for partial dentures by using new materials. In addition to, calculated for von mises and displacement with using of different three materials. Also, at same year, T. A. Mendes et. al., [5], presented the analysis for the protocol of laboratory and clinical of the removable partial prosthesis. Where, the investigation included using technique for laser melting to production the metal framework and analysis for its model by using 3-D model of finite element technique. Therefore, in this work presented the experimental technique to prediction of life for removable partial denture made of polymethylmethacrylate, in addition, using experimental technique to calculate the mechanical properties for its material used. Also, using numerical technique, by using finite element method, to calculate stress distribution on the removable partial denture.

2. Experimental Work

The experimental technique included calculate of the mechanical properties and fatigue life for materials used to production removable partial denture, in addition, the experimental included manufacturing of the removable partial denture made of polymethylmethacrylate. There, can be using the mechanical properties calculated by experimental technique into theoretical technique to calculate the mechanical behaviour for different materials application, [6-8].

2.1. Materials and Denture Manufacturing Steps

Dental materials are special industrial materials which are manufactured and specially designed for use in the field of dentistry. Different dental materials are available with various characteristics according to the purpose of use. Dental materials include temporary dressing and fillings, dental restoration materials (permanent fillings, crowns and bridges) and tools used in the treatment of dental roots. These materials are used in dental printing and prosthetic dentistry. To determine the fairest percentages of the weight of microzirconia particles for this study, we conducted preliminary investigations by using 2.5, 5 and 7.5 wt% mixtures depending on the results and knowledge from relevant literature. In the present study, the dentures were made of PMMA material with the addition of zirconia particles at different weight fractions. After the sample was mixed well, casting was done in a special mould to manufacture compression and dental samples, as follows Figure 1.
2.2. Bite Force by F-Sensor
The force of biting to humans was measured by a specialised device. The force generated as a result of chewing considerably affected the life of the dental material. A type F sensor (Figure 2) was used to determine this force. This device consisted of a mat of sensors that determines the maximum load and the distribution of pressure on the tooth. Then, the pressure data was transferred to the solid work software which distributed stress on the dental material and determine the areas of failure.

2.3. Compression Test and Compression Specimen Preparation
PMMA with different amounts of added zirconia microparticle contents had adequate compressive strength for complete or partial denture applications. The specimen for compression test must be made according to the ASTM stander, [9-11], therefore, the specimen was prepared via special mild manufacturing (Figure 3) according the ASTM D695-15, [12], as shown in Figure 4.
2.4. Hardness Test

Hardness is the property of a solid material that is defined as the surface resistance of the material to penetration, wear and scratching. The value of hardness can be used to predict the strength, structural coherence and the wear resistance of dental materials. The hardness test depended on many factors, such as temperature, intermolecular bonds and structure, as well as the crosslink in chains, volume fraction of particle reinforcement and particle size [13]. The hardness sample made according to ASTM stander, [14-16], where, According to ASTM D2240, [17], hardness test was performed at room temperature by using the hardness test device (shore D), as follows (Figure 5).
2.5. Design and Manufacturing of Fatigue Human Tooth Tester

The fatigue test is an impartment mechanical test of materials, since its test given the life for materials used under dynamic loading, [18-20]. The life of the dental material is extremely important because prolonged useful life decreases the cost and improves the overall health. The fatigue dental tester was built and designed using the requirements of a repeated load. The fatigue device was designed to simulate chewing force by alternating the load at dental loadings. The electrical and mechanical components of the fatigue dental device at each cycle test consisted of the valve of solenoid, pneumatic cylinder (20 mm) bores and a 40 mm stroke. The counter that records the number of cycles was completed which consisted of a control system, an air mixture filter and a pneumatic compressor. All components were mounted onto a frame under a regulator pressure. The applied load value was set according to the F-sensor results, as follows Figure 6, and the sketch of fatigue human tooth tester shown in Figure 7.

Figure 6 Fatigue human tooth tester

Figure 7 Sketch of fatigue human tooth tester
3. Numerical Analysis
The numerical technique include using finite element method to analysis the tooth, made of dental material, stress distribution, by using Solid-Work program under static load. There, the numerical solution required first selected the best element type can be application to analysis its problem, [21-22], and then required input the mechanical properties for materials, [23-24], and then mesh the sketch model for structure, [25-26], and finally calculation the required results.

Then, the Solid 185 element is selecting to analysis the tooth and calculating the stress behavior with applied load. Where, SOLID185 which was defined by eight nodes that have three degrees of freedom per node, that is, the translations in the nodal directions at different coordinates was used for solid structures of 3D modelling. The node was characterised by large strain capabilities, elasticity, large deflection, plasticity, stiffening of stress and creep. This node also had a mixed formulation ability to simulate the deformation of the nearly noncompressible elastoplastic materials and fully incompressible hyperelastic materials.

The boundary condition included dental support which were supported from the bottom of the root by using a fixed support from a static structure and then selecting the specific area, as shown in Figure 8. The maximum applied pressure on top of the tooth at different areas was obtained from the F-sensor device.

4. Results and Discussion
4.1. Compression Test Result
When an object is tested in compression, failure may occur as a result of maximum stresses (ultimate stress) for four groups. Table 1 shows the ultimate strength of the PMMA with different weight fractions of zirconia. The compressive strength increased with the increase in the amount of added zirconia particles at 2.5 wt% and increased by 5 wt%, but the strength decreased slightly at 7.5 wt%. This finding confirmed that silica easily initiated the crack propagation, thereby increasing the brittleness of the composites and decreasing their ductility.

| Groups              | Ultimate stress (MPa) |
|---------------------|-----------------------|
| A PMMA              | 51.7                  |
| B 2.5 wt% of zirconia| 58.1                  |
| C 5 wt% of zirconia  | 68.3                  |
| D 7.5 wt% of zirconia| 61.6                  |

Figure 8. Boundary condition (support and load) and mesh of dental material
4.2. Hardness Test Results
The hardness value of groups by the shore D test is shown in Table 2. The hardness value increased when the weight fraction increased because zirconia had high hardness with respect to PMMA.

| Groups        | Mean value of hardness (shore D) |
|---------------|----------------------------------|
| APMMA         | 71                               |
| B 2.5 wt% of zirconia | 82                           |
| C 5 wt% of zirconia   | 88                               |
| D 7.5 wt% of zirconia | 93                               |

4.3. F-Sensor Results
F-Sensor is an occlusal analysis system consisting of a mat sensor of patented, a USB port and a software that detects the value and timing of bite force on individual dental and patient’s bite stability. The results of the sensor are shown in Figure 9, as follows.

4.4. Dental Life Test
According to the tested specifications, the loads varied between the maximum load obtained from the F-sensor without load. The maximum value of the number of bite load until failure was approximately 28332 cycles at 5 wt% by using the fatigue dental test due to artificial dental materials fail at a higher life than they appear in the fatigue device because load chewing and shedding processes will not be continuous.

4.5. Numerical Analysis Results
The stress distribution was obtained using the Solid-Work program by using static load, as shown in Figure 10. The maximum equivalent stress (0.53 MPa) at the dental material was located in a small area located on the outer surface on the top of the tooth. This value of equivalent stress did not exceed the material stress. Therefore, the tooth did not fail under the static load.
5. Conclusions
In this study, the following conclusions can be drawn,
1. The experimental technique used was a perfect tool can be using to calculate the mechanical properties for partial denture. In addition, the numerical was perfect tool can be using to calculate the life of removable partial denture.
2. Compression strength increased with the increase in weight fraction and then decreased when the weight fraction was 7.5 wt% due to the increased brittleness of the sample.
3. The new device (fatigue dental tester) which was manufactured to measure the life of dental material can determine the quality of the partial denture.

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