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Three-Dimensional Finite Element Analysis of Denture Base Resin Modified by Prepared Polyester Polymer

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Abstract:
The current study aimed to assess the effect of addition of prepared polyester in three concentrations to the polymethylmethacrylate and analyze its effect on the underlying structure in the mandibular arch. Unsaturated polyester was prepared by the condensation polymerization of maleic anhydride with di ethylene glycol and used in three concentrations (1%,3% and 5%) for addition to the polymethylmethacrylate to prepare the denture base. Four specimens were fabricated according to the international standards specifications , Rectangular specimen with specific measures (65mm length, 10mm width and 3mm thickness) was used to measure the modulus of elasticity of the modified poly methylmethacrylate in different concentration. The modulus of elasticity was obtained from Universal testing machine (INSTRON, USA). Then load-deflection curves were recorded by the connected computer software (Bluehill v1.5; Instron Ltd). From load-deflection curves, the elastic modulus was calculated according to following formula: E = FL3/4Ybd3 where E= Flexural modulus (MPa), F=maximum load (N), L=span length (65 mm), Y=recorded deflection when the load is applied at the middle of the beam, b=specimen width (10 mm), d=specimen thickness (3mm). Autodesk Inventor is a Computer-Aided Design (CAD) software developed by Autodesk.it is used to design the model which is mandibular arch for the finite element analysis in this study. The results of the finite element analysis revealed that the sample with 3% polyester showed the better stress distribution and give better results in the Von Mises stress, Equivalent Strain and Displacement values.
Key word: *finite element analysis, denture base, polymethylmethacrylate, Polyester.*

INTRODUCTION

One of the frequent issues affecting oral health, particularly in the elderly population, is tooth loss [1,2]. There are many different treatment techniques available to replace lost teeth, regardless of the underlying cause [3,4].

The most common treatment options for replacing missing teeth are whole or partial dentures because dental implants are significantly more expensive [5]. Generally speaking, there are three types of dental materials utilized to make dentures: metal, ceramic, and resin. Due to its superior mechanical and physical qualities over other polymers, acrylic resin, also known as polymethyl methacrylate (PMMA), is one of the most widely utilized polymeric materials as a denture foundation material [6,7]. Many studies used polyester fibers alone or in combination with other types like polypropylene fibers due to its better esthetics [8]. The salinization procedure used to make the fibers in better attachment with acrylic resin. The use of polyamide fibers will increase the strength of polymethylmethacrylate, especially when used with another type like glass fibers or aramid [9].

-What is Finite Element Analysis (FEA)?

limited number of elements, and because many of the concepts were extrapolated from a theoretically insignificant element to a practically finite-sized element [10]. A specific physical system's behavior is mathematically simulated in FEA. When a continuous structure is broken up into distinct parts, the original structure's characteristics are preserved. Differential equations characterize each of these components, and mathematical models chosen based on the facts being studied are used to solve them [11, 12],3. By recreating the uneven geometries of artificial or natural tissues, FEA enables the creation of models for complicated structures.

Furthermore, FEA enables the modification of those geometries' characteristics, allowing for the application of a force or system of forces to any location and/or in any direction. This provides information on movement as well as the magnitude of the tension and compression forces brought on by these loads (13,14,15)

MATERIALS AND METHOD:

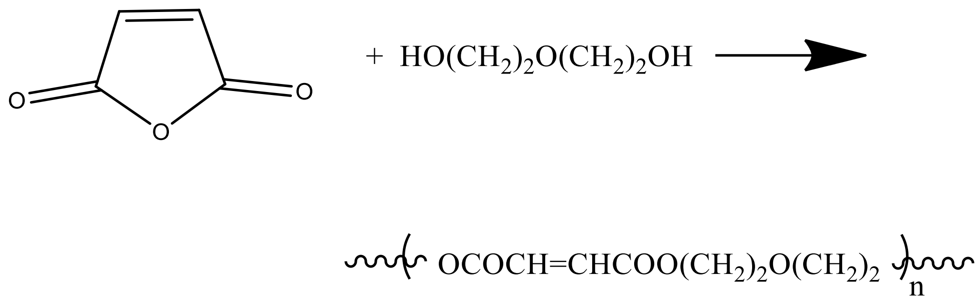
3.7 Preparation of polyester

This polymer was prepared by using condensation reaction between the anhydride monomer (maleic anhydride) and the diol monomer (diethylene glycol). The process was accomplished through interfacial polymerization technique as follows:

Solution 1: consist of 2.75gm (0.025 mole) of diethylen glycol and 2ml of distilled water.

Solution 2: consist of 2.5 gm(0.025mole) maleic anhydride dissolved in 2ml of dry dioxin.

Solution 1 was added to solution 2 in a beaker, interfacial polymerization was followed. the polymer was formed, filtered, and dried under vacuum.



The physical interaction between the prepared polyester and polymethylmethacrylate be sured by Fourier Transform Infrared Spectroscopy Test (FTIR).

For the control group, the stretching bands below 3000 according to aliphatic C-H group at 2843cm^{-1}and 2900 cm^{-1}. The band at 1732 cm^{-1} and 1716 cm^{-1} according to carbonyl group of polyester. The band at 1145 and 1126 cm^{-1} are the finger print of aliphatic C-H bonds, also at 1616 cm^{-1} may be related to CH=CH or C=O group Figure (4.4).

For polyester, the bands at 2922.16 cm^{-1} related to stretching of C-H aliphatic groups. the bands at (1506.41- 1338.60 cm^{-1}) and 1697.36 cm^{-1} are related to bending and stretching of aliphatic C-H group respectively. The band appeared at 2358.94 cm^{-1} is related to charged species which can be formed between the control and the added material and formed a homogenous mixture Figures (2, 3 and 4).

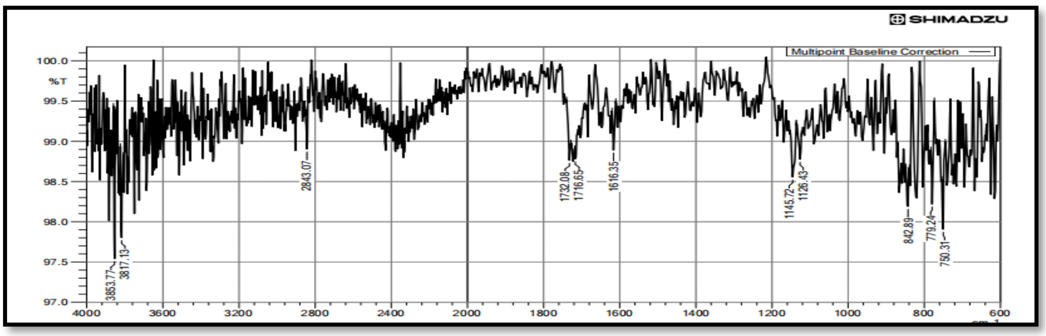


Figure (1) FTIR spectrum of control group.

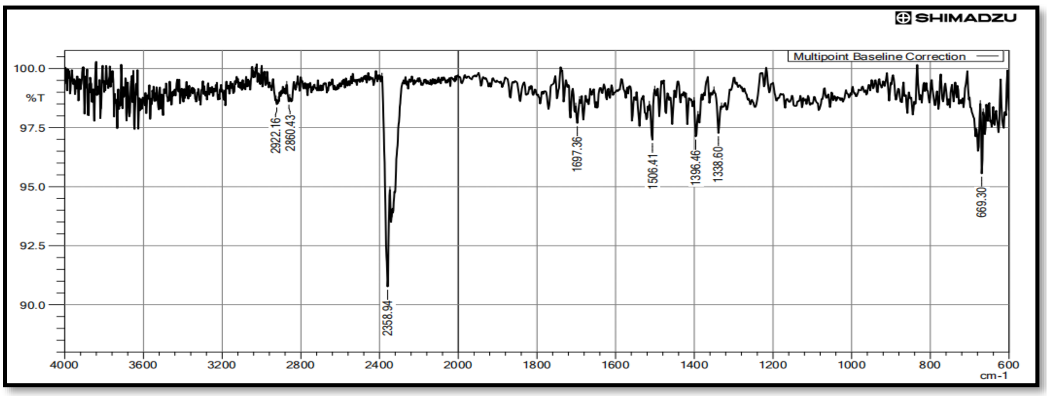


Figure (2) FTIR spectrum of experimental group incorporated with 1% polyester polymer.

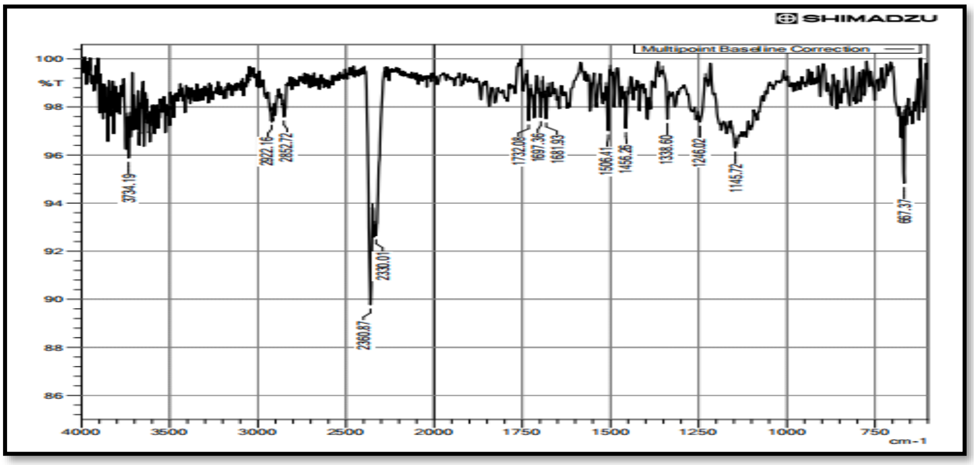


Figure (3) FTIR spectrum of experimental group incorporated with 3% polyester polymer.

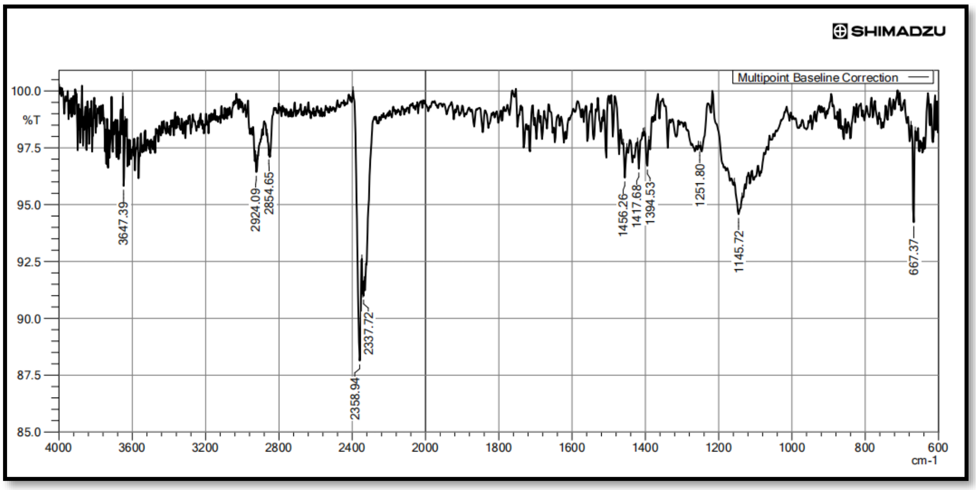


Figure (4) FTIR spectrum of experimental group incorporated with 5% polyester polymer.

Method of measuring the modulus of elasticity of modified denture base resin used in this study

Four specimens were fabricated according to the international standards specifications [16] (ADA. ANSI/ADA Standard No. 139) for three Point Bend Test. Rectangular specimen with specific measures (65mm length, 10mm width and 3mm thickness).

Testing the samples for modulus of elasticity:

The modulus of elasticity was obtained from Universal testing machine (INSTRON, USA.). The specimens were centered on supports of the universal testing machine (three-point loading). While positioning the specimens on the testing machine, care was taken that the central loading plunger was touching the center of the sample (Figure 5). The load was applied gradually perpendicular to the midpoint of specimen strips at the crosshead speed of 0.5 mm /min. The load was applied till maximum capacity of the three-point testing device was recorded.

Then load-deflection curves were recorded by the connected computer software (Bluehill v1.5; Instron Ltd) (Table 1). From load-deflection curves, the elastic modulus was calculated according to following formula: E = FL3/4Ybd3 where E= Flexural modulus (MPa), F=maximum load (N), L=span length (65 mm), Y=recorded deflection when the load is applied at the middle of the beam, b=specimen width (10 mm), d=specimen thickness (3mm) [17].

RESULTS

The informative statistical analysis which showing mean values and standard deviation (SD) of modulus of elasticity results measured in mega
Pascal (MPa)

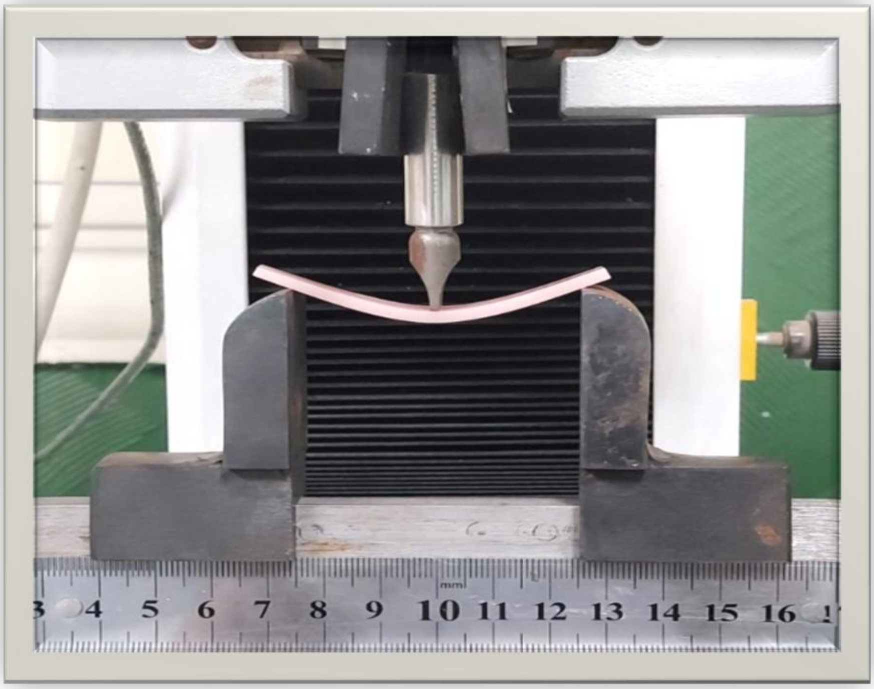


Figure (5) The specimen after testing on the universal testing Machine

FEA helps in studying the stress patterns and their distribution between the tooth and the material used in restoring the natural or missing tooth/teeth structure and predicting the favorable outcome with least chance of failure.

3D simulation of mandibular arch with denture has been performed using an edentulous resorbed mandibular bone and its corresponding denture. In this model, the thicknesses of cortical bone, mucosa, and acrylic denture base were assumed to be 2, 2, and 2.5 mm, respectively [18]. The model was designed by ANSYS software then the analysis was done by using Autodesk Inventor program.

The mechanical properties of different parts of model were taken from (Table 2).

Boundary Conditions

Zero displacement constraints must be placed on some boundaries of the model to ensure an equilibrium solution.

The constraints should be placed on nodes that are far away from the region of interest to prevent the stress or strain fields associated with reaction forces from overlapping with each other Figure (5).

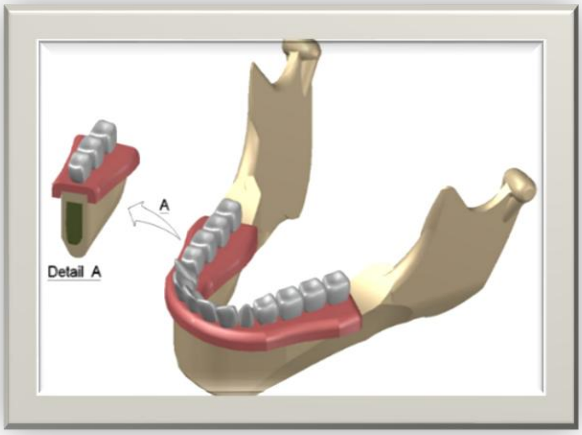


Figure (6): Finite element analysis model

Table (1) Modulous of Elasticity of the prepared polyester polymer

Materials	Modulous of elasticity (MPa)
PMMA+ polyester 1%	2175
PMMA+ polyester 3%	2150
PMMA+ polyester 5%	2100

Table (2): properties of the materials used in this study [19]

Name	General			Stress		
	Mass Density	Yield Strength	Ultimate tensile strength	Young's Modulus	Poisson's Ratio	Shear Modulus
Acrylic	1 g/cm^3	40 MPa	45 MPa	0.00345 GPa	0.45 ul	0.00118966 GPa
Spongy Bone	1 g/cm^3	40 MPa	45 MPa	13.7 GPa	0.3 ul	5.26923 GPa
Cancellous Bone	1.99 g/cm^3	40 MPa	45 MPa	13.7 GPa	0.26 ul	5.43651 GPa
Mucosa	1 g/cm^3	40 MPa	45 MPa	2 GPa	0.45 ul	0.689655 GPa

RESULTS:

Finite element analysis of denture base and underlying structures produced from:
-polyester
polyester 1%
1. Von Mises stress

The high values of Von Mises Stress were observed below the point of force application at the central fossa of the artificial tooth, in the denture base and in the mucous membrane which was (9.06 - 36.26 MPa) in the X, Y, and Z axes respectively. The contour line of the stress values is shown in Figure (4.58).

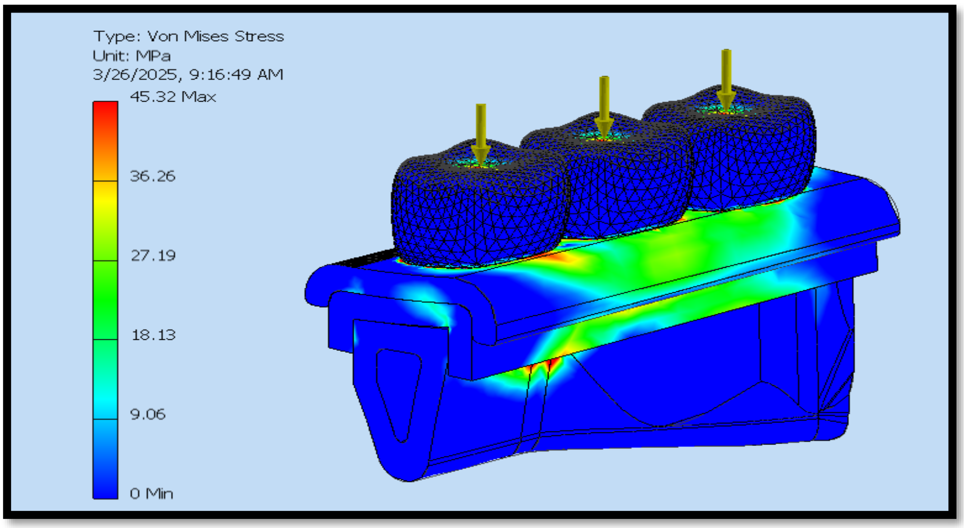


Figure (7) Von Mises stress of polyester 1%

2. Equivalent Strain:

The high values of Equivalent Strain were observed below the point of force application at the central fossa of the artificial teeth and in the denture base which was (0.208– 0.834MPa) in the X, Y, and Z axes respectively. The contour line of the equivalent strain values is shown in Figure (4.59).

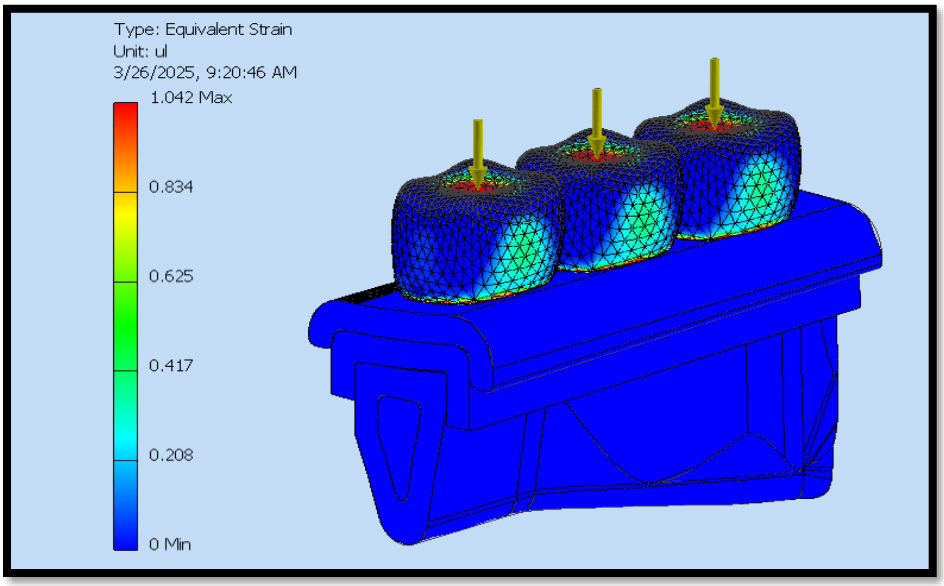


Figure (8) Equivalent strain of polyester 1%

3.Displacement:

The greater amount of displacement were observed below the point of force application including the artificial teeth in the all direction from the base to the bottom which was (0.368- 1.474 MPa) in the X, Y and Z axes respectively. The contour line of the displacement values is shown in Figure (4.60).

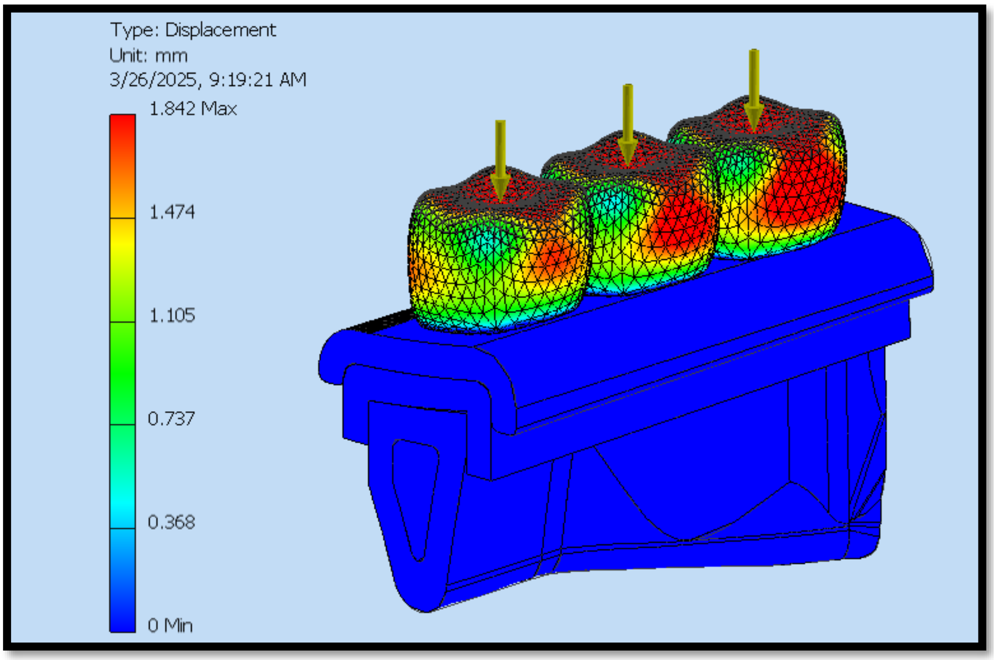


Figure (9) Displacement of polyester 1%

-Polyester3%

1. Von Mises stress:

The high values of Von Mises Stress were observed below the point of force application at the central fossa of the artificial tooth, in the denture base and in the mucous membrane which was (12.23 - 49.32 MPa) in the X, Y, and Z axes respectively. The contour line of the stress values is shown in Figure (4.61).

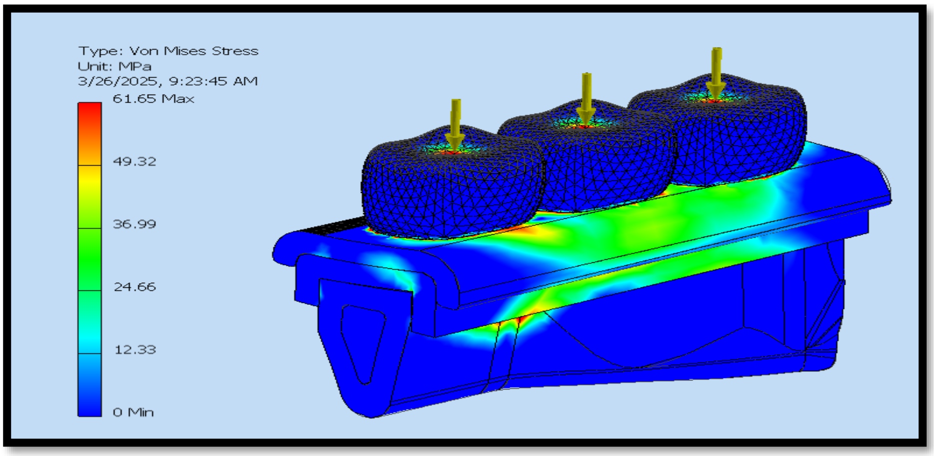


Figure (10) Von Mises stress of polyester 3%

2. Equivalent Strain:

The high values of Equivalent Strain were observed below the point of force application at the central fossa of the artificial teeth and in the denture base which was (0.1981– 0.7924 MPa) in the X, Y, and Z axes respectively. The contour line of the equivalent strain values is shown in Figure (4.62).

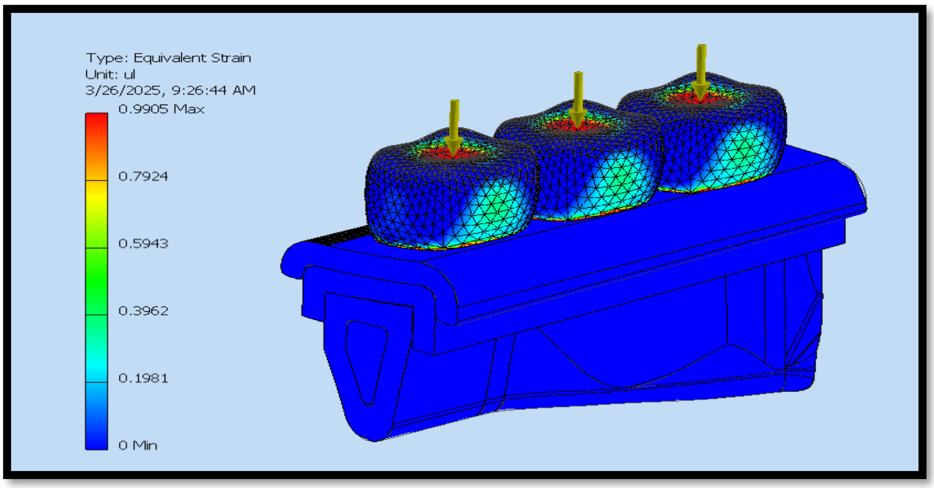


Figure (11) Equivalent strain of polyester 3%

3. Displacement:

The greater amount of displacement were observed below the point of force application including the artificial teeth in the all direction from the base to the bottom which was (0.369- 1.476 MPa) in the X, Y and Z axes respectively. The contour line of the displacement values is shown in Figure (4.63).

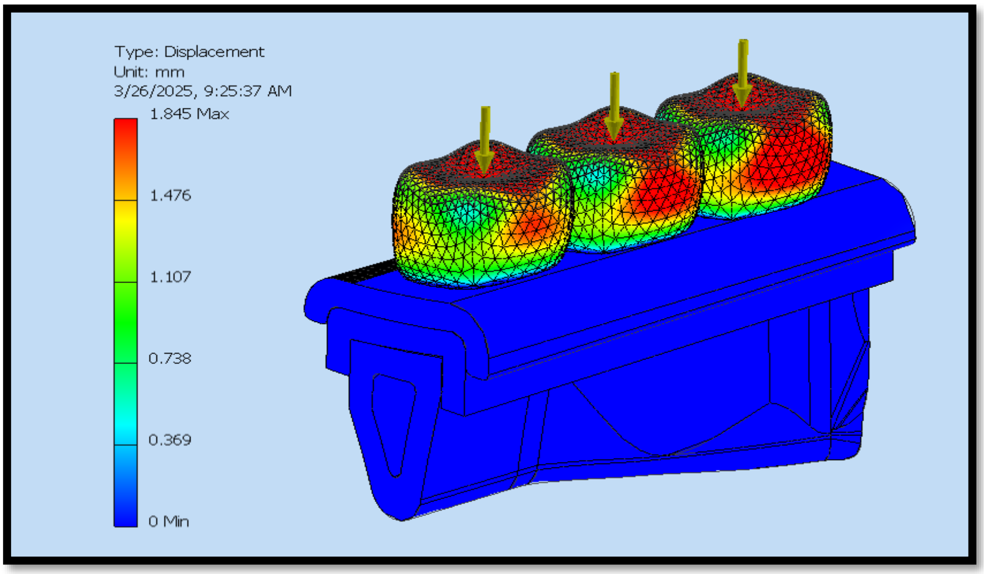


Figure (12) Displacement of polyester 3%

-Polyester5%

1. Von Mises stress:

The high values of Von Mises Stress were observed below the point of force application at the central fossa of the artificial tooth, in the denture base and in the mucous membrane which was (9.51 - 38.03MPa) in the X, Y, and Z axes respectively. The contour line of the stress values is shown in Figure (4.64).

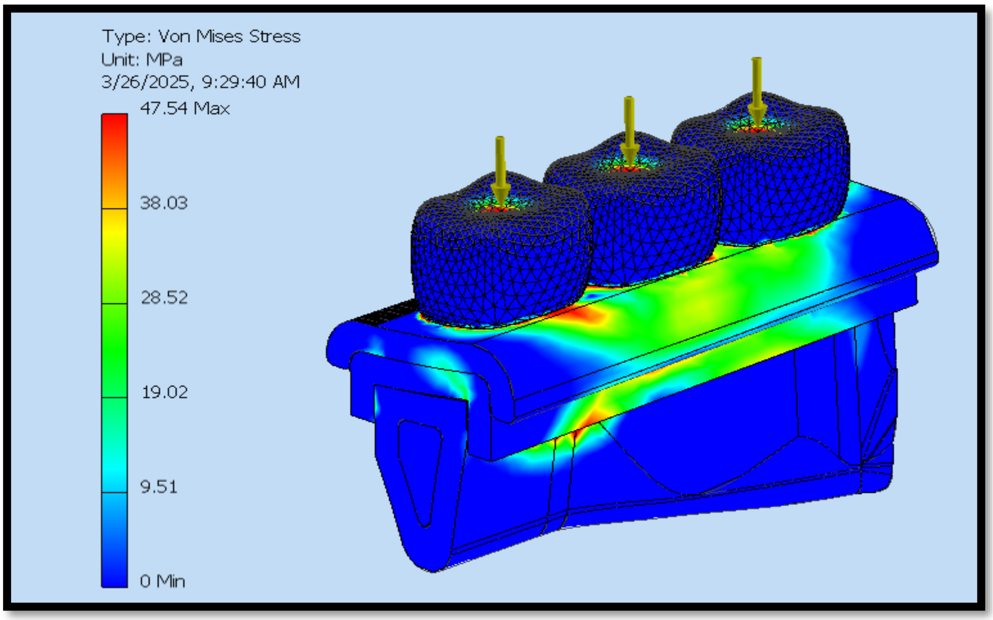


Figure (13) Von Mises stress of polyester 5%

2. Equivalent Strain:

The high values of Equivalent Strain were observed below the point of force application at the central fossa of the artificial teeth and in the denture base which was (0.206– 0.826 MPa) in the X, Y, and Z axes respectively. The contour line of the equivalent strain values is shown in Figure (4.65).

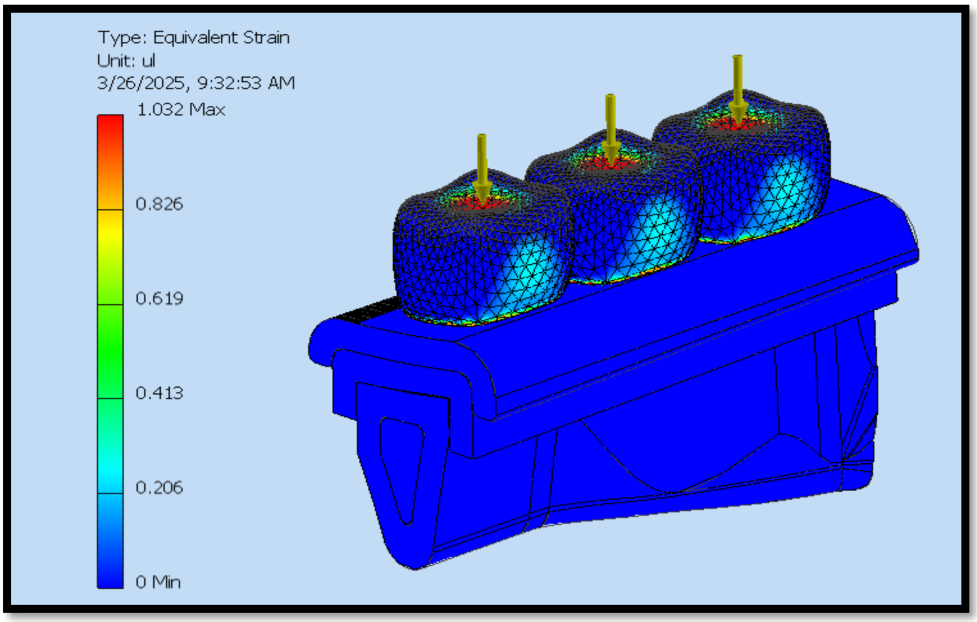


Figure (14) Equivalent strain of polyester 5%

3. Displacement:

The greater amount of displacement were observed below the point of force application including the artificial teeth in the all direction from the base to the bottom which was (0.37- 1.479 MPa) in the X, Y and Z axes respectively. The contour line of the displacement values is shown in Figure (4.66).

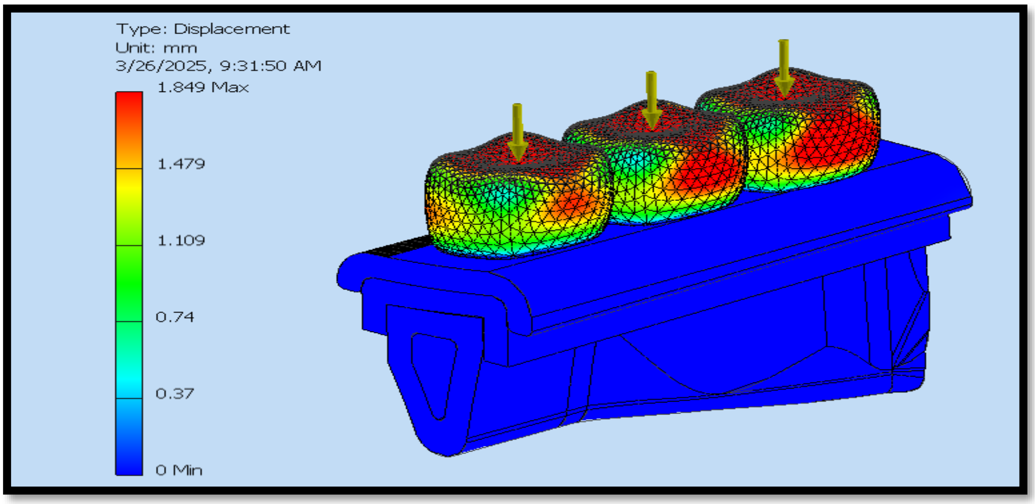


Figure (15) Displacement of polyester 5%

DISCUSSION:

The high values of Von Mises Stress were observed below the point of force application at the central fossa of the artificial tooth, in the denture base and in the mucous membrane which was (14.94- 59.74 MPa) for the control group(9.06 - 36.26 MPa) for 1% polyester group , (12.23 - 49.32 MPa) for 3% ,polyester group,(9.51-38.03MPa)for 5% polyester.

The high values of Equivalent Strain of control group were observed below the point of force application at the tip and the bottom of the artificial teeth which was (0.204 – 0.817 MPa), (0.208–0.834MPa) for 1% polyester group, (0.1981– 0.7924 MPa) for 3% polyester group ,(0.206– 0.826 MPa) for 5% polyester group.

The greater amount of displacement of control group were observed below the point of force application including the artificial teeth in the all dirction from the base to the bottom which was (0.377- 1.509 MPa), (0.368- 1.474 MPa) for 1% polyester group, (0.369- 1.476 MPa) for 3% polyester group, (0.37- 1.479 MPa) for 5% polyester group.

In order to guarantee the passage of vertical occlusal stresses to the underlying supporting structures and lessen the lateral and oblique forces applied to the underlying tissues, a vertical load was given to the premolar teeth's central fossa [20].

The stiffness and rigidity of the material are reflected in its modulus of elasticity [21]. The capacity of a denture base to distribute stresses evenly to the underlying structures depends on the rigidity of the denture framework, even while the flexibility of the denture base helps increase the amount of energy absorbed before breakage [22]. Because denture base materials with high elastic moduli are more resistant to elastic deformation, enabling the production of dentures with thinner bases, a greater flexural modulus—that is, reduced flexibility—is therefore frequently favorable in clinical contexts [23, 24].

The results of this investigation demonstrated that stress was primarily concentrated on the mucosa and alveolar ridges beneath load application sites. These results were consistent with prior research that showed stress concentration was caused by the alveolar ridges in the mucosa and underlying bone at the site of load application [25].

When the denture base material is firmer, the articular disc experiences fewer strains and the load is better distributed across the mandibular supporting structures [26].

The use of soft liners increased stress on denture supporting systems [27,28]. The denture base showed the highest level of stress concentration, followed by the cortical bone.

CONCLUSION:

When comparing the three concentrations of the prepared polyamide polymer with the control group (polymethylmethacrylate), it is possible to draw the following conclusions within the limitations of the current study: 3% of polyester polymer added to polymethylmethacrylate yields better results in the Von Mises stress, Equivalent Strain, and Displacement values.

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