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# EFFECT OF SANDBLASTING SURFACE TREATMENT ON THE BOND STRENGTH AND SURFACE ROUGHNESS BETWEEN THE 3D-PRINTED DENTURE BASE AND SILICON-BASED SOFT LINER

Sara Maher Shaaban[*] , Sara Mohamed Bahaa El-Din [**] ,
Shahenda Ahmed Abdallah[***] *and* Tarek AbdAllah Mahmoud[****]

## ABSTRACT

**Purpose**: The study was conducted to evaluate the effect of surface treatment through sandblasting on the bond strength between the 3D-printed denture base and silicon-based lining material.

**Material and Methods:** Twenty dumbbell-shaped specimens were fabricated from 3D-printed denture base material, grouping of the specimens was carried out into the following: **group I** (control group): (n=10) The specimens relined without surface treatment and **group II** (experimental group): (n=10) The specimens received surface treatment with 125 $\mu$m $Al_2O_3$ airborne-particle abrasion before relining with silicon-based soft liner. After relining, a universal testing machine was used to measure the tensile bond strength for all the specimens, and the debonded surfaces were visually examined to detect the mode of failure. Surface roughness was measured and surface topography was observed by Atomic Force Microscope (AFM), the scanned area measured 10*10 $\mu$m with a number of data points 256*256, a scanning rate of 1 Hz.

**Results:** The effect of sandblasting on the tensile bond strength between the 3D-printed denture base and silicon-based soft lined was statistically significant P-value $\leq$ 0.05, and the statistical analysis for the values of surface roughness before and after sandblasting revealed a high significance P-value $\leq$ 0.001.

**Conclusion:** Surface treatment of the 3D-printed denture with125 $\mu$m $Al_2O_3$ prior to silicon-based soft-liner application, improves the surface roughness and enhances the tensile bond strength. Which in turn decreases possible failures that occurred in the bond of soft-lined dentures.

**KEYWORDS:** 3D-printed denture, tensile bond, soft liner, surface roughness.

* Lecturer, Removable prosthodontics Department, Faculty of Dentistry, Badr University in Cairo
** Lecturer, Removable Prosthodontic Department, Faculty of Oral and Dental Medicine, Al-Azhar University
*** Lecturer at Dental Biomaterials Department, Faculty of Dental Medicine for Girls, Al-Azhar University
****Lecturer, Removable Prosthodontics Department, Faculty of Dentistry, Modern University for Technology and Information

## INTRODUCTION

The development of preventive dental medicine had increased in the last decades, but edentulous continues to be a major problem for healthcare providers [1]. The complete dentures are constructed mostly for older edentulous patients. The conventional method requires many sessions which can be a real burden to some patients and the denture cannot be remade if it is got lost or fractured [2,3].

Recently digital fabrication of complete dentures has become popular. Two principles of CAD-CAM techniques are available, milling and rapid prototyping, and they had reported acceptable results clinically [4]. The three-dimensional printing technique of construction has become popular in the dental field as an alternative to conventional techniques along with the development of CAD-CAM manufacturing technology, as well as its special polymers availability [4-7]. Digital techniques allow facilities as the digital data that can be saved and shared as the ability to design and simulate changes three-dimensionally [8].

The digital technology used in dental prosthetic manufacturing includes subtractive and additive methods [9]. The 3D printing technique offers much superiority over milled and conventionally constructed dentures. The superiorities include 3D printers' affordable price, compared to milling technique machines, also through the reduction in the amount of wasted materials, printing of multiple dentures at the same time, and complex designs with fine details that can be printed without any difficulty. [10].

Subtractive techniques have many drawbacks including excessive waste of the material, and excess material being processed, which makes it difficult to reuse this material and will be discarded. These discarded materials will be an economic and environmental burden. Another drawback is that; cutting tools lose their sharpening with time and it is difficult for the milling machine to cut areas of undercuts or positions that are inaccessible to the milling cutter used in the milling process [10]. The additive method of denture manufacturing causes a reduction in the wasted material [4].

Soft liners have been indicated for cases with atrophic and thin mucosa, and for residual ridge irregularities and undercuts, it is also needed after alveoloplasty and implant surgeries, and for patients suffering from anorexia. Liners also decrease the amount of force transmitted to the underlining edentulous ridge, but these liners have many problems which may be led to their failure. These problems include loss of resilience and porosity, but the debonding and separation from the fitting surface of the denture is still the most serious problem [4, 11-13].

The durability of the liner adhesion to the denture base is a critical issue, as the weak bond leads to food and bacterial stagnation, color changes, poor oral hygiene, and finally tearing off the lining material from the denture base [14,15].

The denture bases manufactured by the 3D-printing technique presented a significant reduction in the bond with soft, and hard chair side lining materials than that with injected and milled denture bases [16]. The factors affecting the bonding quality between the denture base, and liners include denture base and soft-liner chemical structure, bonding agent effect, lining material layer thickness, thermal stress, and bond strength. [15].

Different values of bond strength were recorded between the denture bases constructed by the 3D-printing technique and the lining material, depending on the technique of surface treatment applied to the denture base [18]. The reduced values for soft liner bond strength reported with denture bases constructed by the 3D-printing technique compared to denture bases constructed by conventional technique under the same conditions; appear to be due to bonding agent interaction and chemical composition differences between denture bases and soft-liner materials. It's obvious that; bonding strength can be improved by reaction enhancement between adhesive and denture bases, but there is still limited research working on the improvement of the reaction between 3D-printed denture base and the bonding agent. [18, 19].

It was stated that; when the 3D-printed denture bases were treated with sandblasting alone or sandblasting together with adhesive, the bonding strength with the liner was enhanced. This is when compared to denture bases constructed by 3D-printing techniques without any surface treatment or adhesive application [19].

In reference to some authors, certain lining materials cannot achieve a proper bond to denture bases fabricated by the 3d printing technique. So, it was suggested to apply an adhesive or sandblasting before application of the soft lining material, which can significantly improve the bond strength and result in a bond similar to that formed between the milled or conventional dentures to soft liner materials [19, 20].

Soft liners and 3D-printed denture bases' bond strength require more research to be precise; whether there is a special bonding technique to be applied, to get a stronger and more stable bond between the denture bases constructed by 3d printing technique and soft liners [10].

Additional studies are required to study printed denture bases and the printers used for their fabrication to enhance their progress together with increase their uses in removable prostheses [21].

## MATERIAL AND METHOD

The study was conducted to assess how sandblasting affects tensile bond strength between 3D-printed denture base material and silicon-based soft liner. The study had the approval of the Ethics Committee of the BUC-Institutional Ethical Committee and given approval code; BUC-IACUC-230306-16.

### Specimens' preparation

20 specimens were fabricated to be dumbbell-shaped 75 mm in length, 7 mm, 12 mm, in diameter at the thinnest and thickest portion. The specimens were fabricated from 3D-printed denture base material for testing the tensile bond strength. (Figure 1). (n=10/test).

Using the computer-aided design, software of a 3D printer was used (Chitubox, CBD Technology Co., Ltd, China), and specimens were 3D-printed. A total of 20 samples were printed, and the thickness of the layer was designed to be 50 µm/ layer using 3D denture base material (Nextdent,3d denture base, Netherland) and the 3D printer (Next dent 5100 printers. Netherland) as follows; using LC 3D Mixer, the material container was shacked very well for five minutes thoroughly, (NextDent 3D systems, Vertex Dental B.V., Netherland). This step is considered very important before the material dispensation in the tank, for loosening the possible sediment from the bottom of the material container.

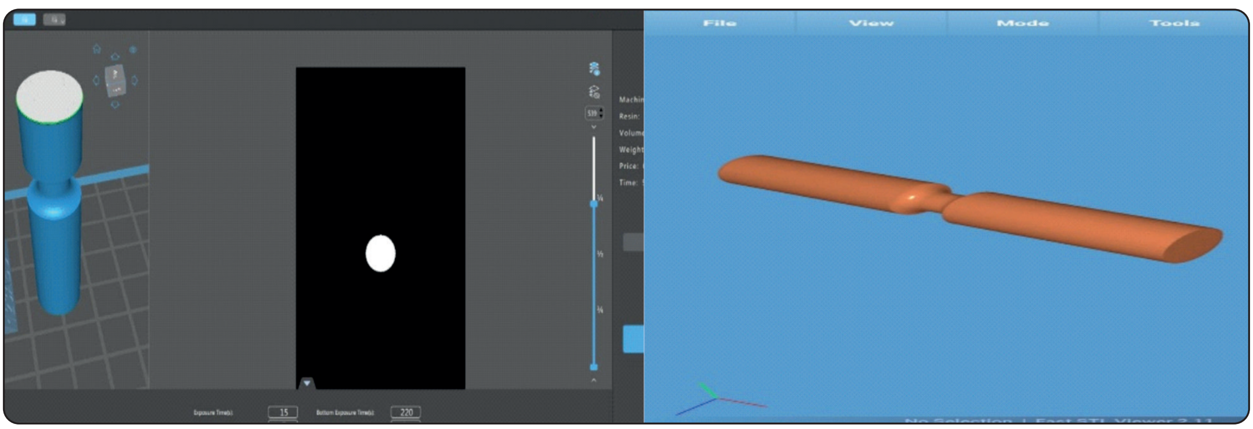


Fig. (1): Digital designing for 3D-printed denture base samples with dimensions (75*12*7mm)

After digital printing, an alcohol bath using ethyl alcohol 99.9% for three minutes was applied to all specimens. This step is essential to clean the printed specimens and to remove any residuals of the material. Clean alcohol was used for extra two minutes of cleaning. The printed sections were allowed to rest for 10 minutes after cleaning and drying to ensure that there were no residuals from the alcohol in the printed sections.

The printed sections were placed in the UV light polymerization unit (LC-D Print Box, Nextdent, Netherland) as the post-curing processing is recommended for 10 minutes, the printed sections were submerged in glycerol for final polymerization to reach an optimal cure.

All the specimens were numbered, and invested in a dental flask using dental gypsum. The flasking was made to maintain the soft-liner thickness to be three mm standardized for all specimens and to allow easy application of the soft-liner materials in in-vitro conditions. All the 20 specimens were sectioned, and 3 mm from the thinnest portion was removed with a diamond saw (DEMCO, Manila, Philippines) under continuous water cooling, a digital caliper was used to measure the amount of material removed then all sections' cutting surfaces were smoothened with abrasive paper of 400 grit.

**Specimens Grouping**

Specimens were equally divided into two groups:

**Group (I)**: 10 specimens of 3D-printed denture bases received silicon-based soft liners without surface treatment (control group).

**Group (II):** 10 specimens of 3D-printed denture bases received sandblasting treatment before application of the silicon-based soft liner.

To permit water saturation for the resin of the denture base, all specimens were placed in distilled water at 37 degrees for 48 hours.

**Surface Treatment**

The bonding surface for the experimental group to be sandblasted was subjected to 125 µm aluminum oxide airborne abrasive from a 10 mm distance with a pressure of 0.2 megapascals for 10 seconds in a circular movement. This was done using the air abrasion device. Rinsing of specimens under running water and air-drying was carried out to ensure a clean bonding interface free from any abrasion remnants. The other 10 specimens are kept without any surface treatment so, they served as a control experimental group.

**Silicon-based soft-liner application**

The two sections of each specimen were stabilized at the flask 3mm apart from each other to allow space for Mucopren Soft liner material (Kettenbach, Germany). The soft-liner adhesive was painted to the specimen's bonding surface using Mucopren adhesive (Mucopren Adhesive; Kettenbach Dental USA) and allowed to be set for 30 seconds.

Another layer of the adhesive material was applied and allowed to be set for 90 seconds according to manufacturer instructions. Mucopren was applied by dispensing gun, the flask counterpart was closed, and the liner material was allowed to be set under pressure, then the specimens were submerged for 30 min. in water at fifty degrees.

The excess liner material was trimmed, and a thin layer of Mucopren Soft sealant was applied (Kettenbach Dental, USA).

**Bond strength evaluation**

After the soft liners had been set group I and II specimens were taken from the flask and submerged for 24 hours in water before measuring the tensile bond strength. Measuring tensile bond strength was made by universal test machine. The adhesive strength of the specimens were assessed by measuring the strength of tensile bond with

Model 3345 testing machine from Instron Industrial Products, USA with a 5 kN load cell. The resulting data was analyzed by Bluehill lite software from Instron Instruments (Figure 2).

The upper plate of the universal testing machine gripped one end, while the lower end was gripped by the machine's lower base using tightening screws. The vertical load was increased slowly by 1mm per minute until the upper and lower section was totally separated from each other associated with a decrease in the load-displacement curve which was recorded by Bluehill Lite software.

Required amount of load for the separation to occur between every two sections, was recorded in Newton by the computer software Bluehill Lite. For the bond strength to be expressed in mega Pascal (MPa), the load in Newton was divided by interfacial area. TBS(tensile bond strength)= F (maximum force) / Area (cross-sectional area of the specimens).

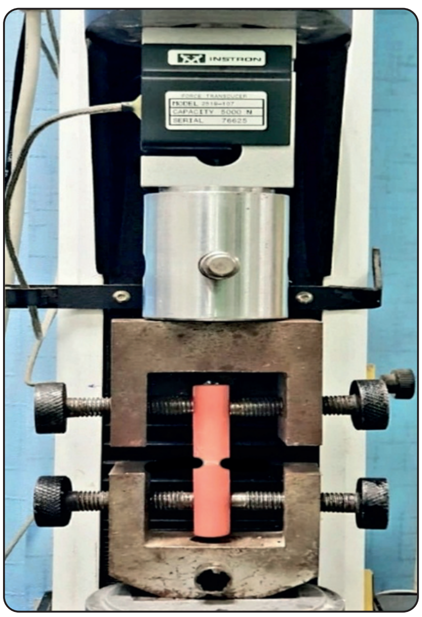


Fig. (2): The universal test machine was used for tensile bond strength measurement

## Roughness measurements

Surface roughness was measured for the specimens of groups I and II before the application of the soft liner using an Atomic Force Microscope (AFM), (model: Auto probe cp-research head). The microscope scanned area of 10*10 $\mu$m with 256*256 data points were used, the rate of scanning was1 Hz. The AFM was used in contact mode using a nonconductive silicon nitride probe(Model: MLCT-MT-A.), (Bruler Corporation, Billerica, Massachusetts, USA.) for controlling the scan parameters the pro-scan 1.8 software was used and image analysis was made using IP 2.1 software.

The specimens used for scanning surface roughness were firmly placed on magnetic specimen stubs with adhesive tape. The surface roughness was 3 directionally expressed in X, Y, and Z directions. The specimen's surface was imaged in contact mode at (25-32°C) room temperature. The images were captured using a Silicon Nitride cantilever with a spring constant of 0.03 N/m. The vertical deflection of the cantilever was used to obtain the topographic images. The vertical deflections of the cantilever were evaluated using the laser spot that was reflected from the upper surface of the cantilever into an array of photo detectors. During scanning the force was kept constant in the range of 2.5nm between the tip and the surface. The dimensions of the scanned areas were 10 ×10 $\mu$m. Using computer software, the topographical data of the surface were measured.

## The mode of failure evaluation

Visually, the specimens were inspected to reveal the mode of failure in separated specimens. Regarding failures, it was presented to be three types, the specimen showing deboning at the junction between the printed denture base and the liner was called adhesive failure while the damage that occurred within the bulk of the soft liner was referred to as a cohesive failure, however, a mixed failure described the presence of a combination of both of them.

## RESULTS

Tensile testing was suggested by (ASTM) the American Society of Testing Materials for measuring the quality of the bond between the denture base and soft liner and it was applied in the present study.

An Independent T-test was used to assess the surface sandblasting effect on the bond strength. P value ≤ 0.05 was considered statistically significant (95% significance level), and the P-value ≤ 0.001 was considered highly significant (99% significance level). The statistical software SPSS (version 25, IBM Co. USA) was used for analyzing the data.

### Sandblasting effect on the bond strength:

The mean of bond strength was (0.931±0.22 MPa) in the 3D-printed denture base lined with silicon based soft liner, after treatment with sandblasting the value was increased to (1.17±0.34 MPa). Following the independent t-test, the difference between the values was considered to be significant (P- value ≤ 0.05).

### Sandblasting effect on surface roughness:

According to an independent t-test, the mean value of surface roughness was (0.25±0.0012 um) in the 3D-printed denture base, after treatment with sandblasting this value increased to (0.28±0.0048um), the difference between the values was significant (P-value ≤ 0.001).

TABLE (1) Compare mean value ±SD of tensile bond strength between 3D printed denture base and soft liner with and without sandblasting treatment.

| Denture base | Without sandblasting | With sandblasting | P-Value* |
|---|---|---|---|
| **3D printed** | 0.931±0.22 | 1.17±0.34 | 0.05 $^{S}$ |

*- $^{S}$ statistically significant at P ≤ 0.05*

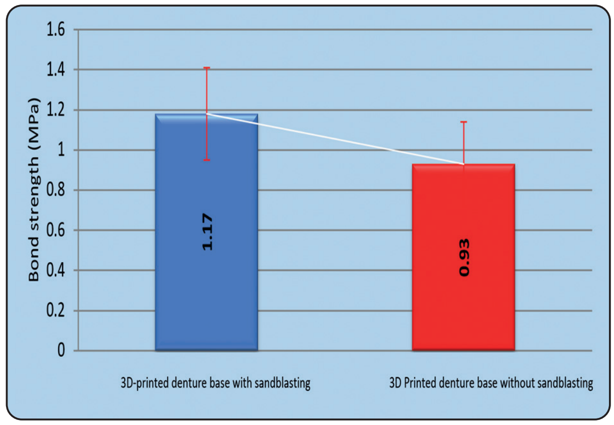


Fig. (3): Bar chart depicting the mean and SD of bond strength for 3D printed denture base lined with silicon-based with and without sandblasting treatment

TABLE (2) Comparison of Mean ±SD of 3D printed denture base surface roughness with and without sandblasting treatment.

| Denture base Surface roughness | Without sandblasting | With sandblasting | P-Value |
|---|---|---|---|
| **3D printed** | 0.25±0.0012 | 0.28±0.0048 | **0.000$^{HS}$** |

*- $^{HS}$ highly significant P-value ≤ 0.001*

### Mode of failure analysis

The mode of failure distribution for the test specimens revealed that adhesive failure was (90%) that was the predominant type in both groups, followed by mixed failure which was (10%). The cohesive type of failure didn't observe at both types (0%). The distribution of mode of failure was equal in group I &II. Accordingly, the type of failure was not dependent on the surface treatment of the base and soft liner with and without sandblasting treatment.

## DISCUSSION

Recently, prosthetic dentistry uses 3d printing technology for denture fabrication, which allows variety for new research developments in clinical and laboratory fields. Provided that such techniques and material biological, chemical, mechanical, and physical behavior are still being detected [(21,22)]. The characteristics of bonding between the lining material and denture base were evaluated through measuring; peel, shear, and tensile bond strengths. The reliable test to evaluate bond strength between the soft-lining materials and denture base materials was suggested to be the test for tensile bond strength [(13)].

It was stated that; a major concern that limits the use of soft-liners, was confirmed to be debonding from the denture base material [(23)]. Studies that compared the strength of the tensile bond between different denture bases, and relining material and the lowest value was revealed by denture bases fabricated by 3D-printing technique. A variety of methods were presented to enhance the bonding characteristics of the soft lining material to the denture bases [(17, 24)].

The chemical structure of the soft liner, layer thickness in addition to thermal and mechanical stresses in the oral cavity, tear strength, and adhesive nature were all considered to be contributors to the bonding and debonding quality of the lining material [(25,26)].

In the present study, different materials of denture base and soft liners were used. Changing the denture base and lining material chemical composition cannot be achieved since it is an inherent property of the material, therefore the bonding quality was improved by sandblasting of the printed denture base using (125 um) aluminum oxide airborne abrasive. This treatment showed a statistically significant increase in the tensile bonding strength of the silicon based soft liner to the printed denture base.

A significant difference in the tensile bond strength between the printed denture base material and soft liner after being sandblasted has been recorded in the current study. This was also proven in the study done by Park et al., their study detected that the bond strength in the group treated by sandblasting showed a higher significant value than that not receiving any surface treatment or adhesive application [(18)].

The impurities from the denture surface were eliminated through sandblasting, which in turn showed improvement in the mechanical bonding by increasing the bonding surface area and surface roughness [(27)]. Similar results were proven in a study made by Al Taweel et, al. who assessed the sandblasting of denture base by 110 $\mu$m $Al_2O_3$-particle abrasion and showed that there was a remarkable increase in the tensile bond strength of the lining material to conventional denture base [(28)].

The tensile bond strength between the printed denture base and soft liner after different surface treatments for the denture base was measured by Li et al. including monomer application, and air abrasion with 125 µm. $Al_2O_3$. The result of this study showed that; the bond strength highest value was detected in the sandblasting group, and the tensile bond strength was significantly increased [(29)].

Sandblasting is a process that includes a stream of $Al_2O_3$ particles sprayed under pressure against the material surface to be bonded [(30)]. Different protocols for sandblasting are available depending on the size of the particle abrasion which ranged from 30 to 250 $\mu$m. Sandblasting will remove the loose contaminated layers and consequently, the surface will be roughened providing bonding with the adhesive and mechanical interlocking [(31, 32)].

There was a significantly increased in the surface roughness recorded in group II of the current study which indicated a form of larger surface area for the bond strength and consequently showed increased tensile bond strength. This record was in compliance with Storer [33] who stated that; the strength of the bond between the soft liner and the denture base resin was improved when sandblasting was done to the denture base before soft liner application as sandblasting provide slight irregularities to the surface that will enhance the mechanical interlocking.

In the present study, there was an increase in the readings of the surface roughness of the 3d printed denture base to 0.28±0.0048 um when sandblasted with aluminum oxide. This was attributed to the size of the aluminum oxide airborne abrasion which allowed easy penetration of the lining material through the irregularity of the resin surface made by sandblasting and enhanced the bond between the 3D-printed denture base and the soft liner.

In the current study, the value of surface roughness before and after sandblasting was within the clinically relevant threshold of 0.2 $\mu$m as stated by Fernandez et, al [34].The mean value of surface roughness in the current study showed to be 0.25±0.0012 while in the study made by Gad et, al. [35] showed to be 0.12± 0.02 this may be due to surface polishing of the specimen made by the authors using polishing machines however the same study showed raising at the record of the mean for surface roughness of the same specimens to be 0.22 ±0.02 after being thermocycled

Mccabe et, al. [36] stated that it is essential to interpret the results of the tensile bond strength test to analyze the mode of failure. If the material had failed cohesively, this shows that; the bond strength is greater than the material's internal strength. Assessment for the mode of failure between the printed denture base material and silicon-based soft liner before and after being sandblasted revealed that the relining material and base resin bond strength was lower than that between the liner molecules of the soft liner.

Koseglu et, al. [37] revealed that the increase in the bond strength is usually associated with a change in the mode of failure however, there was no change in the mode of failure in the current study, before and after sandblasting also there was an increase in the strength of tensile bonding after sandblasting.

Limitations for the present in vitro study were that the tensile bond strength was evaluated without the simulation of masticatory forces as well as saliva which maintains a very humid environment.

## CONCLUSION

Surface treatment of the 3D-printed denture with125 $\mu$m $Al_2O_3$ before the silicone-based soft-liner application improves surface roughness together with an enhancement in tensile bond strength. And that decreases the possible failures that occur in the bond of soft-lined dentures.

### Ethics Approval

Ethical approval (BUC-IACUC-230306-16) was given by the Ethics Committee of the BUC-Institutional, Badr University, Cairo, Egypt.

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This research didn't receive any external funding.

There are no funding conflicts to declare.

### Conflict of Interest

The authors claimed no conflict of interest that could influence the work reported in this research.

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