ORIGINAL RESEARCH

Mechanical, Surface, and Optical Properties of PMMA Denture Base Material Modified with *Azadirachta indica as* an Antifungal Agent

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Abstract

Aim and objective: The present study assessed the influence of *Azadirachta indica* (AI) powder on the mechanical, surface, and optical properties of heat-polymerized *polymethyl methacrylate* (PMMA) denture base material.

Materials and methods: A total of 300 heat-polymerized PMMA acrylic resin specimens were fabricated with dimensions of $65 \times 10 \times 3.3 \pm 0.01$ mm for flexural strength, $50 \times 6 \times 4 \pm 0.01$ mm for impact strength testing, and $15 \times 2 \pm 0.01$ mm for surface roughness, hardness, and translucency testing. The specimens were distributed into six groups ($n = 10$) based on AI powder concentration: An unmodified control group and AI powder–modified groups with 0.5, 1, 1.5, 2, and 2.5 wt% of acrylic resin powder. Universal testing machine was used to measure flexural strength and Charpy's impact tester for impact strength. Surface roughness, hardness, and translucency were assessed using a profilometer, Vicker hardness tester, and spectrophotometer, respectively. One-way analysis of variance (ANOVA) and posthoc Scheffe's test were utilized; $p \leq 0.05$ was considered a statistically significant difference.

Results: ANOVA showed no significant differences in terms of impact strength ($p = 0.175$) and surface roughness ($p = 0.371$), while significant differences were detected in terms of flexural strength, hardness, and translucency ($p = 0.001$). According to *post hoc* Scheffe's test, there was a significant decrease in flexural strength for AI groups ($p < 0.001$) except 0.5% AI group ($p = 0.66$), while impact strength had no significant difference between AI groups ($p = 0.175$). Hardness had an insignificant difference between control and modified groups ($p>0.05$), with exception of 2.5% AI group ($p = 0.001$). For translucency, a significant difference was found between control and all modified groups ($p<0.05$).

Conclusion: Incorporating AI powder into heat-polymerized denture base material did not significantly alter impact strength, surface roughness, or hardness, except at 2.5% AI concentration, where hardness decreased. On the contrary, flexural strength and translucency were significantly affected.

Clinical significance: This study contributes to establishing a new approach for denture stomatitis disease treatment and prevention with the lowest adverse effect on denture properties.

Keywords: *Azadirachta indica* powder, Flexural strength, Hardness, Impact strength, Surface roughness, Translucency.

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Introduction

Denture-induced stomatitis (DIS) is a prevalent oral disease identified by inflammation and redness of the denture-bearing mucosal membrane. It may cause extreme oral pain and impaired ability to speak or eat.[1] The prevalence of DIS among denture wearers has been reported to reach up to 70%.[1] The etiology of DIS could be attributed to many factors, such as poor oral hygiene, reduced salivary flow, mucosal membrane damage, and microbial infections.[2] The most significant factor in the pathogenesis of DIS is the adherence and colonization of *Candida albicans (C. albicans)* on denture surfaces, followed by biofilm formation.[3] Effective antifungal modalities are required to eradicate *C. albicans* adhesion to the denture base.[4]

Several antifungal methods can be utilized for DIS prevention and treatment, such as application of topical antifungal agents, use of denture cleaning agents, modification of the denture base surface, and incorporation of antimicrobial compounds into the acrylic resin denture base material.[5] The topical application of antifungal agents and immersion of the denture base into cleaning agents are both effective therapies for DIS.[5] However, their effects depend on continuous and accurate use.[6] They may also cause

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toxic adverse effects and are only effective for a short period.[5,6] Moreover, denture cleansing agents negatively alter the denture base's physical properties, such as changing denture base color and increasing its surface roughness (Ra), rendering it a suitable medium for plaque accumulation.[7]

Surface modification by coating the denture base can reduce the Ra and increase the hydrophilicity, which will result in the reduction of *C. albicans* adhesion.[5] However, denture retention and adaptation might be affected by coating due to surface obliteration.[5] The coating may also be disturbed by mechanical and chemical cleaning, leading to an increase in Ra and, consequently, an increased tendency toward *C. albicans* adhesion, discoloration, and poor esthetics.[5] Conversely, modifying denture bases by incorporating antimicrobial agents into the acrylic resin might eradicate the disadvantages of the coating by embedding the antimicrobial agents inside the resin matrix.[5] Natural antifungal agents, such as henna (*Lawsonia inermis*), neem (*Azadirachta indica*), and thymoquinone (*Nigella sativa* seeds), are inexpensive, easily approachable, and less toxic than the conventional antifungal agents.[5,8] These have shown a significant role in preventing fungal adhesion and proliferation.[9]

Azadirachta indica (AI), commonly known as neem, is a medicinal tree native to the Indian subcontinent.[10] Traditionally in India, various parts of the *A. indica* tree and products derived from them have been used for their medicinal properties.[10] The global interest in *A. indica* is due to its active compounds, which have been studied by researchers over the past 60 years; its biological activity and medicinal effects have been proven.[11] *A. indica* products have antidiabetic, anti-inflammatory, antifungal, antimalarial, antibacterial, antiviral, and anti-carcinogenic properties.[10–13] Hamid et al.[8] in 2019 investigated the effect of *A. indica* powder incorporation into heat-polymerized and auto-polymerized polymethyl methacrylate (PMMA) acrylic resin materials with different AI powder concentrations: 0, 0.5, 1, 1.5, 2, and 2.5 wt%. They concluded that adding AI powder into acrylic resin materials significantly decreased the adhesion of *C. albicans* in all tested concentrations and might be utilized as a method for DIS prevention.[8]

Although PMMA denture base material modified with AI powder has antifungal activities, its mechanical, surface, and optical properties had not been assessed. The current study aimed to investigate AI powder's influence on the mechanical, surface, and optical properties of heat-polymerized PMMA denture base material. The null hypothesis of the present study was that adding AI powder to heat-polymerized PMMA denture base material would not alter the mechanical, surface, and optical properties.

Materials and Methods

Specimen Size

The study was conducted in Imam Abdulrahman bin Faisal University, College of Dentistry. Sample size calculation revealed that a total of 300 specimens were required to conduct the present study. The specimens were distributed into six groups (n = 10) according to AI powder concentration. It consisted of an unmodified control group (without AI powder) and five AI powder-modified groups with concentrations of 0.5, 1, 1.5, 2, and 2.5 wt% of acrylic resin powder. International Organization for Standardization (ISO) 1567[14] and ISO 1567:1999/Amd 1:2003.[15] Specimens were fabricated with dimensions of 65 × 10 × 3.3 ± 0.01 mm for flexural strength (n = 60) and 50 × 6 × 4 ± 0.01 mm for impact strength (n = 60), and specimens were prepared with edgewise V-notch having a depth of 1.2 mm, leaving a residual depth beneath the notch of 4.8 mm. To fabricate specimens with V-notch, at the middle part, at the center of the mold along with the thickness of 1.2 mm, a V-shaped projection was incorporated, resulting in V-notch in wax specimens, while a disk shape in dimensions of 15 × 2 ± 0.01 mm was fabricated for Ra, hardness, and translucency (n = 60/test).

PMMA/AI Composite Preparation

Locally collected fresh AI leaves were obtained (250 gm) and kept in the shade to dry in the air. After drying, a microgrinding machine was used to obtain the AI powder. Then, a microfiltration paper was used to filtrate and obtain the finest AI particles. Using an electronic balance (Denver Instrument GmbH, Goettingen, Germany), the AI powder was weighed and added to the heat-polymerized PMMA powder (BMS 014 powder; BMS Dental, Capannoli, Pisa, Italy) at concentrations of 0.5, 1, 1.5, 2, and 2.5 wt%. Next, AI powder was mixed using an electric mixer for 60 seconds, followed by stirring in a blender for half an hour at 400 rpm to attain an even AI powder distribution.[8,9]

Specimen Processing

Using metal molds with specific dimensions and modeling wax (Vertex Dental B.V., Soesterberg, Netherlands), wax specimens were obtained. The specimens were invested in dental stone type III (Fujirock EP; GC Corporation, Tokyo, Japan) inside a metal flask (61B Two Flask Compress, Handler Manufacturing, Westfield, New Jersey, USA). Wax elimination resulted in established mold spaces. While the stone remained warm, a thin separating medium (162-800-00; VandexIsoliermittel GmbH, Hamburg, Germany) was placed. According to the manufacturer's instructions, the previously prepared PMMA or AI composite was mixed in a porcelain jar and packed at the dough stage inside the created mold spaces under pressure. The flasks were closed, then left beneath a bench press for half an hour. Processing was performed following the conventional curing method by inserting the flasks inside a heat curing machine (KaVo Elektrotechnisches Werk GmbH, Biberach, Germany) at 74°C for 8 hours and then at 100°C for 60 minutes. The flasks were taken out and bench cooled prior to deflasking. Following deflasking and complete polymerization of the material, a tungsten carbide bur (HM 79GX-040 HP; Meisinger USA, Centennial, Colorado, USA) was utilized to eliminate excess resin from the specimens. For specimen finishing, a tungsten carbide bur (HM 79GX-040 HP; Meisinger USA, Centennial, Colorado, USA) was used with a thin cross cut at 18,000 rpm. Then, coarse grain followed by fine-grain cylindrical rubber top burs was used (Super Acrylic Polisher; Long Dental). Next, a soft bristle brush with a fine pumice mixture was used for specimen polishing. With the aim of standardizing the specimens, the final polishing was performed for all the specimens utilizing a mechanical polisher (MetaServ 250 grinder-polisher; Buehler GmbH, Braunschweig, Germany) with a polishing cloth disc (TexMet C10 in, 42-3210; Buehler GmbH) and 0.05 µm polishing suspension (MasterPrep polishing suspension; Buehler GmbH) in wet conditions for 2 minutes at 100 rpm. In order to check the specimen dimensions, a digital caliper within 0.01 mm accuracy was used (Neiko 01407A Electronic Digital Caliper). Finally, specimens were kept in distilled water for 1 week at 37°C in order to minimize residual monomer contents.[8,9]

Flexural Strength

The fracture load was determined by performing a three-point bending test utilizing a universal testing machine (ElectroPuls E3000, Instron, UK). At the specimen's midpoint, a load was applied with 5 mm/min cross-head speed until the specimen fractured. The fracture load of the specimens was recorded and then calculated using the equation $FS = 3WL/2bd^2$, in which FS = flexural strength, W = fracture load, L = distance between the supports, b = specimen width, and d = specimen thickness.[16]

Charpy's Impact Test

The impact strength was measured using Charpy's impact testing machine (Digital CharpyIzod impact tester, XJU 5.5; Jinan Hensgrand Instrument Co., Ltd., Jinan, China). The specimen was removed from the water and then placed on the specimen supports of the testing apparatus. Each specimen was horizontally placed with a 4 cm distance between the two fixed supporters. In the mid-span of the specimens and on the opposite side of the V-notch, a pendulum (5.5 J) was released in order to fracture the specimen and then displayed the recorded impact strength (kJ/m^2) value digitally.[16]

Surface Roughness

By utilizing a non-contact optical interferometric profilometer with 0.01 mm resolution (Contour GT; Bruker Nano GmbH, Berlin, Germany), specimen Ra readings were obtained. Every specimen was horizontally positioned below a standard camera at 20× magnification and scanned across an area approximating 0.43 × 0.58 mm. Every specimen's surface was radially scanned at five sites. In order to attain the Ra values, calculations of the surface profile numerical values and the Ra average value for every specimen were performed. Finally, in order to ascertain pit features, a software package was used to analyze the obtained images (Vision 64; Bruker Nano, Coventry, UK).[9]

Hardness

The corresponding tester (Wilson Hardness; ITW Test and Measurement GmbH, Shanghai, China) was prepared with a Vickers diamond and utilized to conduct hardness tests. Each specimen was subjected to a load of 25-gf for 30 seconds at three different sites. The final average hardness values of the three indentations were calculated for every specimen.[17]

Translucency

A spectrophotometer (Color-Eye® 7000A, X-Rite) was utilized to measure reflectance values. A small aperture viewing area was selected with dimensions of 10 × 7.5 mm. Utilizing the supplied white tile and black trap, spectrophotometer calibration was achieved in accordance with the manufacturer's recommendations. Specimens were held against the port and supported by white or black reference material, and then the support arm was locked. The Commission Internationale de l'Eclairage (CIE) system has L^*, a^*, and b^* coordinates, which were used in the disk color measurements. CIE was used on disks against each background. For every specimen, three values were recorded, and the average was directly calculated. Finally, data were arranged, and translucency was analyzed utilizing the following,in which TR stands for translucency.[18]

$$equationTR = [(L^*\text{white} - L^*\text{black})^2 + (a^*\text{white} - a^*\text{black})^2 + (b^*white - b^*black)^2]^{1/2}$$

SEM and TEM Characterization

Powder and mixtures: The size, shape, and structure of the AI powder were revealed by using scanning electron microscopy (SEM) (SEM, TESCAN VEGA3 LM model, Tescan Orsay Holding Kohoutovice at 20 kV and magnification of x 4000) and transmission electron microscopy (TEM) (TEM, Morgagni 268, FEI at 80 kV and magnification of x180,000) (Figs. 1A and 1B), while the distribution of the AI powder in the PMMA powder before heat polymerization was evaluated by SEM at a representative magnification of x 800 (Figs. 1C to 1E). The SEM of the pure PMMA specimen was also examined in order to see the morphology and structure of the pure PMMA spheres. For the mixture, two specimens were selected, one with the lowest concentration of AI (PMMA/0.5%AI) and the second with the highest concentration of AI (PMMA/2.5%AI) in order to confirm the distribution of the AI material in the PMMA matrix. For SEM, all the specimens were gold coated in order to overcome the charging effect of the low-conductive nature of the materials. SEM and TEM images of the materials were recorded and collected in Figure 1.

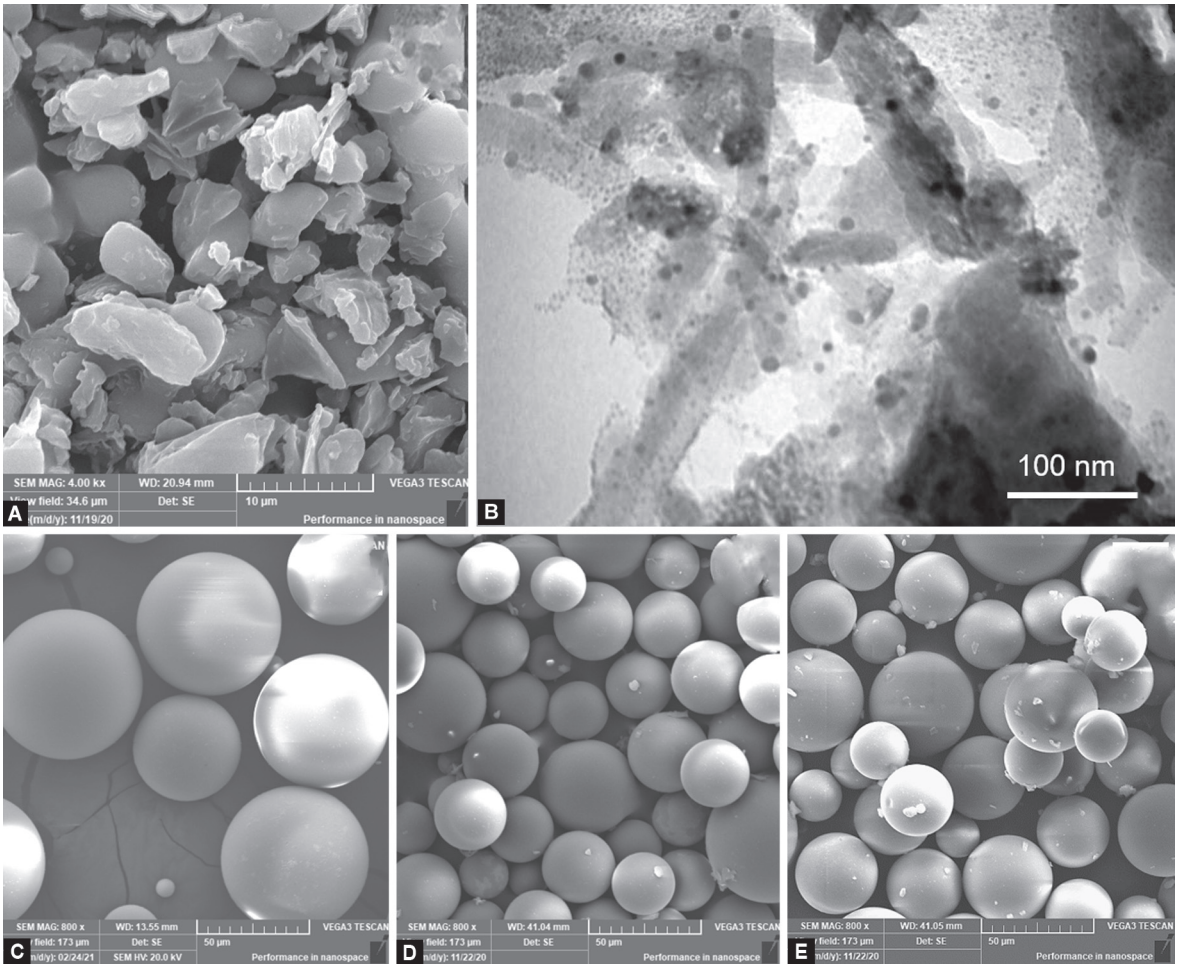
After the flexural strength tests, the cross-sectional surface of the fractured specimens was examined using SEM. The SEM was operated at a medium accelerating voltage of 20.0 kV. For better image acquisition, the charging effects were minimized by coating the specimens with gold (Quorum, Q150R ES, UK). The SEM micrographs of the control PMMA and composite PMMA (PMMA/AI matrices) specimens were obtained at varied scan areas to capture the different surface features and determine the type of failure. The cross-sectional images of both the control and composite specimens are displayed at a representative magnification of x 500 (Fig. 2) and x1000 (Fig. 3). For a better comparison between different specimens, the electronic micrographs are represented at the same magnifications.

Statistical Analysis

A statistical package for social sciences (SPSS V.23) was used for data analysis. In the descriptive analysis, the mean and standard deviation was calculated for each group. For inferential statistics, the normality of the data was tested first. Insignificant p values of Shapiro–Wilk test revealed that the data are normally distributed. Hence, a one-way analysis of variance (ANOVA) was used to test significance in mean differences between the groups. In case of significant results of ANOVA, post hoc Tukey's test was used for pairwise comparison. A p value less than 0.05 was considered statistically significant.

Results

ANOVA (Table 1) showed a statistically significant variation in mean flexural strength due to a change in concentration ($F = 344.296$, $p<0.001$). Mean value and standard deviations, and significances between groups were summarized in Table 2. Pairwise comparison through post hoc test in comparison to control group showed a significant decrease in flexural strength for AI groups ($p<0.001$) except 0.5%AI group ($p = 0.66$). Among AI–modified groups, there was a significant decrease in flexural strength as AI increased

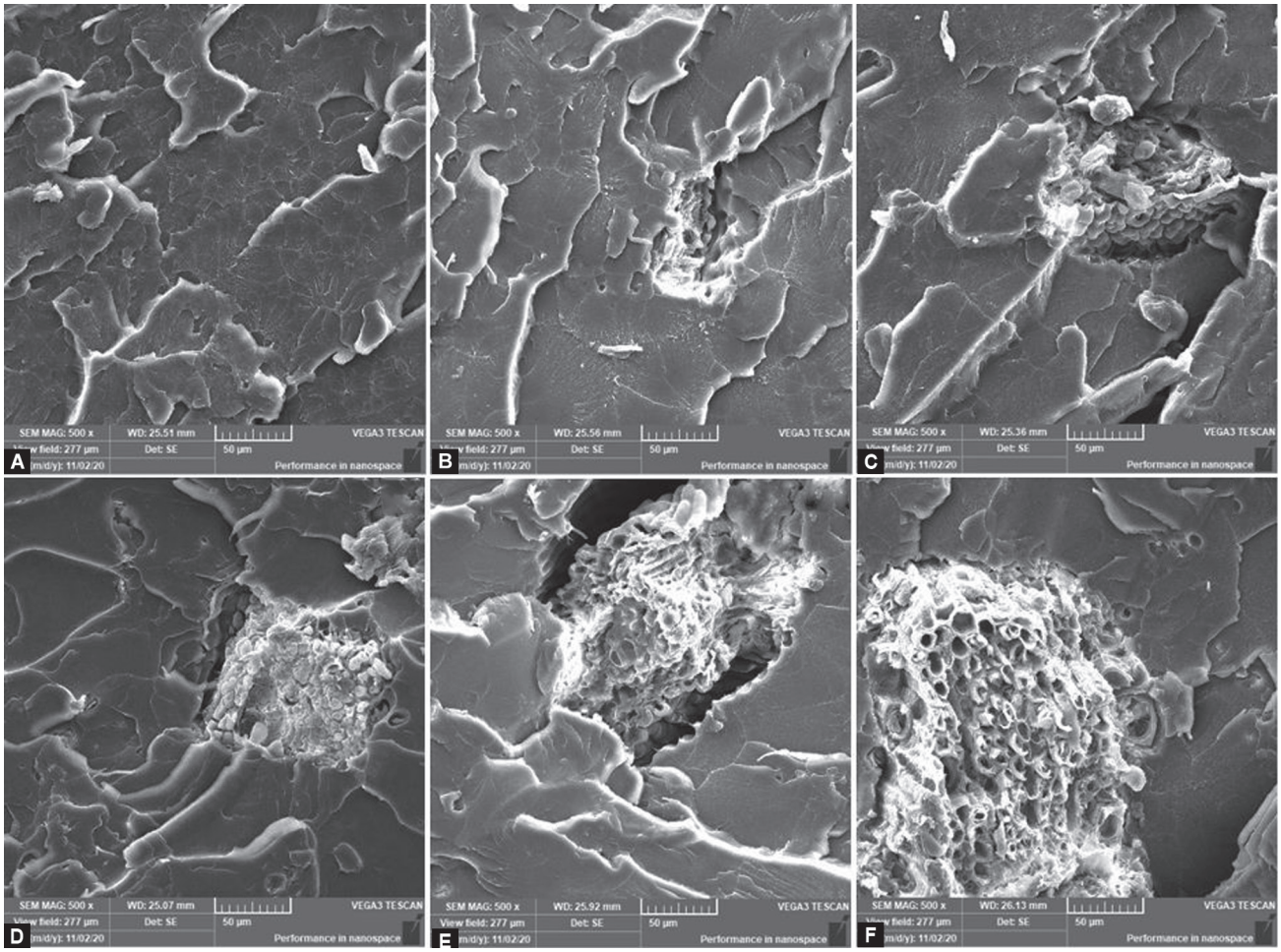


Figs 1A to E: Representative SEM and TEM images; (A) SEM image of AI powder (x4000); (B) TEM image of AI powder (x180,000); SEM micrographs (x800) (C) Pure PMMA powder; (D) Physical mixture of PMMA/0.5%AI; (E) PMMA/2.5%AI

except 1.5% AI versus 2%AI showed no significance (p = 1.0). In terms of AI groups, the highest flexural strength value was reported with 0.5%AI (85.63 ± 1.18), while the lowest value reported with 2.5%AI (61.97 ± 2.20). ANOVA (Table 1) showed no significance in impact strength between control and AI groups as well as between AI groups (F = 1.613, p = 0.175). Furthermore, in impact strength, the trend was the same as flexural strength. There was a continuous decline in mean due to an increase in concentration; however, it was not found statistically significant (Table 2). Among AI groups, the highest impact strength value was reported with 0.5%AI (12.39 ± 1.71), while the lowest value reported with 2.5%AI (11.74 ± 1.56).

ANOVA analysis (Table 1) showed an insignificant difference in Ra (p = 0.371), whereas a significant difference was found between groups for hardness and translucency (p = 0.001). Therefore, a post hoc Scheffe's test was performed for pairwise comparison between groups. Table 2 shows the means and standard deviations for Ra, hardness, and translucency. In comparison to the control group, Ra results displayed an insignificant difference between specimens modified with AI powder (p>0.05). Between modified groups, the highest surface roughness was found in the 2.5%AI (0.26 ± 0.04), while the lowest was found in the 0.5%AI (0.17 ± 0.02) (Fig. 4). In terms of hardness, there was an insignificant difference between the modified groups and the control group (p>0.05), with the exception of the highest AI powder concentration, 2.5% AI (p = 0.001). The pairwise comparison displayed an insignificant difference in hardness between all the modified groups, except for 2.5% AI when compared to 1% AI (p = 0.002) and 2.5% AI when compared to 1.5% AI (p = 0.010). Among modified groups, the highest hardness value was found in the 0.5% AI group, with a mean value and standard deviation of 32.36 ± 2.19, and the lowest in the 2.5%AI group (29.71 ± 2.86). All modified groups' translucency was significantly less than the control group (p<0.05). The pairwise comparison between all the groups was significant, except between the 0.5% AI and 1% AI groups (p = 0.991). Within the modified groups, the 0.5% AI had the highest translucency value, with a mean value and standard deviation of 19.478 ± 1.00, while the 2.5% AI had the lowest value (10.159 ± 0.862).

SEM and TEM results show that the AI powder consists of varied morphology, such as it contains nanosheets, nanofibers, and nanospheres (Fig. 1A). For the AI powder, the TEM image shows the physical and uniform surface dispersion, whereby the nanospheres are in the range of 5 to 100 nm (Fig. 1B). SEM images of the pure and the PMMA or AI mixtures show the microspheres



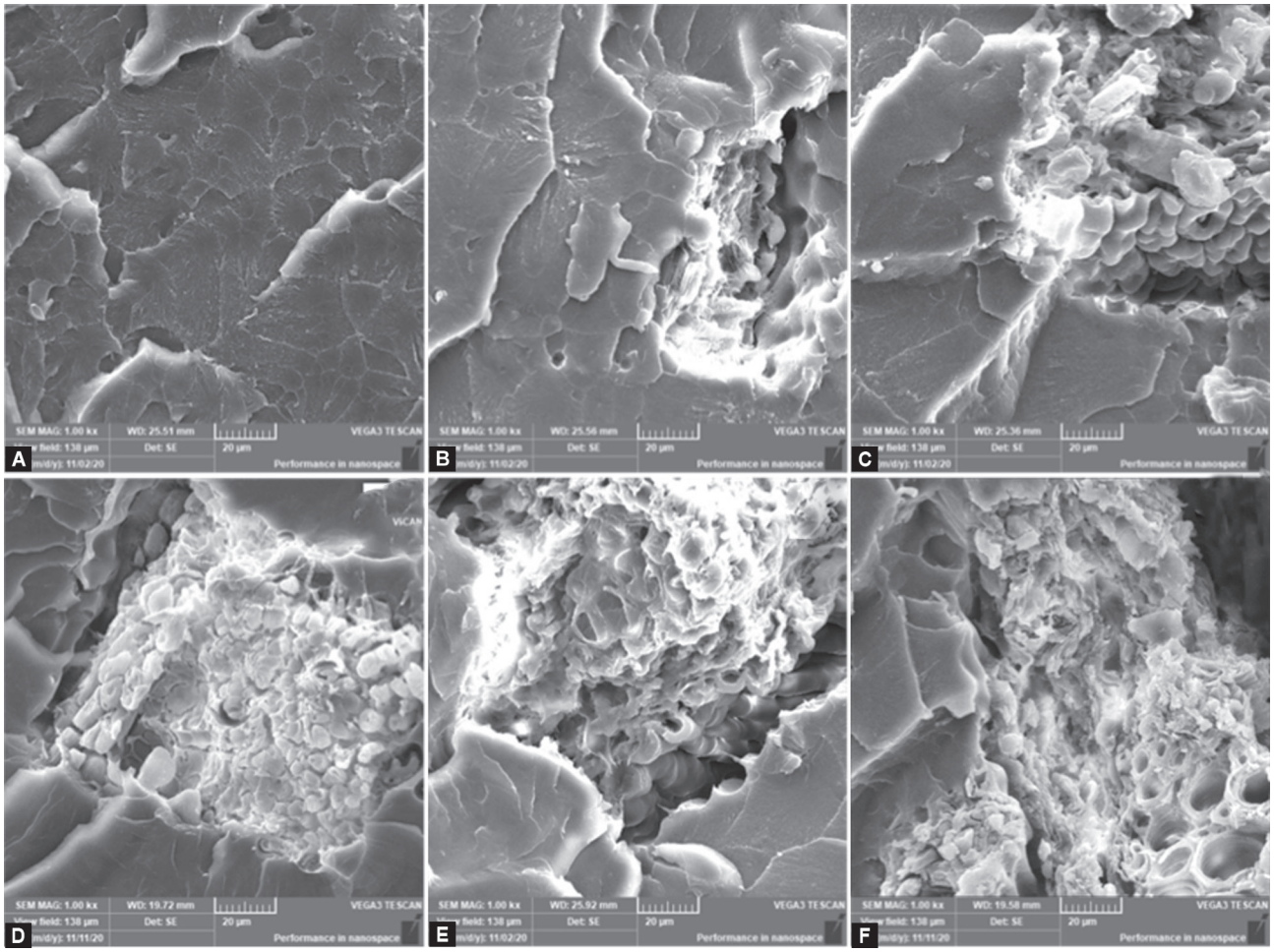
Figs 2A to F: Representative SEM image (x500) of fractured specimens. (A) Control; (B) 0.5%AI; (C) 1%AI; (D)1.5%AI; (E) 2%AI; (F) 2.5%AI

of the PMMA and the particles of the AI powder (Figs. 1C to 1E). In the pure specimen, the PMMA spheres show the clean and pure surface morphology without any other material (Fig. 1C). For the mixture specimens, SEM images show the distribution of the AI powder within the PMMA powder (AI particles are bright in color and dotty in appearance), indicating the uniform dispersion of AI material in the PMMA powder (Figs. 1D and 1E).

The representative images of the flexural tested specimens' surface are displayed by two representative magnifications, x500 (scan area of 277 µm) (Fig. 2) and x1000 (scan area of 138 µm) (Fig. 3). The surface morphology of the control specimen was greatly altered after the inclusion of AI in relation to increasing AI concentration. The control specimen displayed a uniform lamellae structure with the absence of voids (Fig. 2A), while the modified specimens showed the appearance of voids and AI particles in the form of clusters or agglomeration (Figs. 2B to 2F). The number of clusters and the size of the agglomeration are increased with the increase in AI concentration in the PMMA matrix. Large clusters of AI particles were clearly seen for the specimens with 2% AI and 2.5% AI (Figs. 2E to 2F). It can be seen that the lamellae structure that appeared for 0.5–1.5% AI specimens looks similar to the control group, while slightly changed to faint lamellae for 2% AI and ended by smooth background with 2.5% AI, reflecting a brittle fracture. It was observed that the composite matrix showed particle clusters and gaps in the fractured surface (Figs. 2E and 2F), suggesting the addition of higher concentrations of AI yielded poor adhesion between PMMA resin and AI particles, which result in the drop in mechanical strength. On the contrary, the intermediate filler ratio (1 and 1.5wt%AI) showed a strong bonding due to interfacial adhesion between PMMA resin and AI particles, bearing deformation energy to enhance the net flexural strength of the modified specimens (Figs. 2C and 2D).

Discussion

Providing a denture base with an antifungal property could have a significant positive impact on denture wearers. However, the mechanical, surface, and optical properties should not be considerably altered and should remain within the acceptable clinical values. The antifungal effect of AI powder incorporated into denture base material had been confirmed in a previous study;[8] however, the mechanical, surface, and optical properties of the denture base were not investigated. The present study investigated the effects of AI powder incorporation into heat-polymerized PMMA denture base material on its mechanical, surface, and optical properties. The results displayed an insignificant effect on impact strength and Ra and a significant

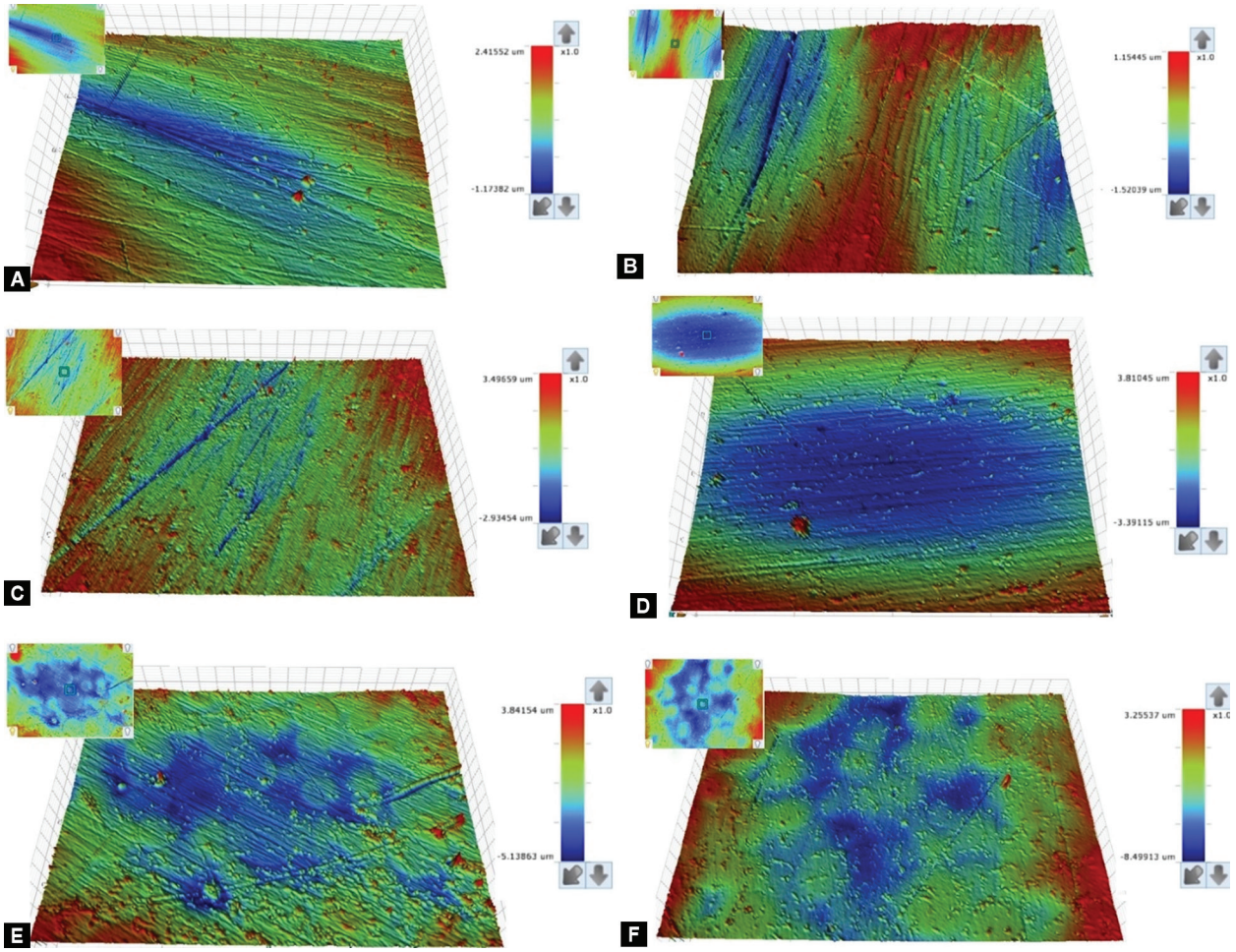


Figs 3A to F: Representative SEM image (x1000) of fractured specimens. (A) Control; (B) 0.5%AI; (C) 1%AI; (D)1.5%AI; (E) 2%AI; (F) 2.5%AI

decrease in flexural strength, hardness, and translucency. Hence, the null hypothesis stating that the incorporation of AI powder into heat-polymerized PMMA denture base material would not alter the mechanical, surface, and optical properties was partially rejected.

The denture base is exposed to flexural stress during function. Moreover, it is commonly supported by unequal alveolar ridges caused by the different patterns of bone resorption.[9] Hence, the denture base should have high flexural strength to prevent fracture during flexural loading and prolong its performance.[9]According to the results of the current study, flexural strength was shown to be significantly decreased as the AI concentration increased except for the 0.5% AI group. However, all mean values of tested AI concentrations apart from 2.5% AI group were higher than the American Dental Association recommendation for flexural strength minimum acceptable value (65 MPa).[19] This reduction might be attributed to the loosely attached AI clusters in the matrix, which behaved as a stress concentration centers that negatively affect specimen's flexural strength.[9] Moreover, AI particles in the resin matrix might act as impurities that could interfere with the material polymerization, hence, leading to an increased residual monomer that acts as a plasticizer affecting the mechanical properties.[20] Furthermore, chemical bonding is absent between AI and PMMA particles.[21] Gad et al.[20] assessed the effect of henna incorporation into PMMA flexural strength, and the results showed a significant decrease in flexural strength at any henna concentration. Another study conducted by Gad et al.[9] showed that more than 1.5% thymoquinone addition to PMMA had a significant decrease in the flexural strength, which is similar to the present study results.

Low impact strength of the denture base is one of the contributing factors, which causes denture failure. Sudden collide or accidental dropping of the denture during the daily performance is usually provoking impact failures.[22] Hence, the denture base's ability to endure impact forces is a crucial factor to enhance its durability.[23] The result of the current study showed an insignificant difference between the impact strength mean values of the control group and AI–modified groups, as well as between the AI–modified groups. The impact strength values decreased as the AI concentration increases. This reduction might be due to the absence of bonding between the AI particles and the PMMA resin matrix, and as the AI concentration increases beyond the saturation limit, it starts to form clusters that act as a stress concentration area in which cracks start to propagate and consequently fracture occurs.[24] Although there is a lack of scientific evidence regarding the influence of natural substrate addition to PMMA on its impact strength, a study was conducted by Al-Harbi et al.[24] to investigate the impact strength of PMMA



Figs 4A to F: Representative surface roughness images of tested specimens based on different AI powder concentrations of heat-polymerized acrylic resin. (A) Control; (B) 0.5%AI; (C) 1%AI; (D) 1.5%AI; (E) 2%AI; (F) 2.5%AI

modified with nanodiamonds.It concluded that impact strength values were decreased with increasing the nanodiamond particles' concentration, which is in agreement with the current study results.[24]

Denture base Ra had been shown to be directly associated with oral tissue health, as the increase in Ra is directly related to increased *C. albicans* adhesion and dental plaque accumulation, as reported by several studies.[17,25] Von Fraunhofer and Loewy[26] studied the factors affecting microbial colonization of oral prostheses, and they reported that an increased Ra of denture base surface aided in *C. albicans* adherence and biofilm formation. The results of the present study showed an overall insignificant increase in Ra among all modified groups. However, adding more than 1.5% AI powder caused Ra levels to increase above the clinically acceptable value of 0.2 µm.[27] This might be attributed to the voids created on the resin surface after finishing and polishing, which were caused by loosely attached AI clusters ranging from small to large size on the resin surface in proportion related to AI concentration.[9] According to Nawasrah et al.,[28] the addition of henna powder to heat-polymerized PMMA denture base material in concentrations of 1, 2.5, 5, 7.5, and 10 wt% showed a significant increase in Ra value in all tested concentrations.

Denture base hardness influences its abrasiveness. Adequate denture base hardness is required in order to resist abrasion and wear.[29] Hardness can affect the denture base surface properties due to its influence on scratch resistance during clinical use and denture cleaning, as well as its effect on the ease of material finishing.[30] According to the present study results, the addition of 0.5, 1, 1.5, or 2% AI powder to heat-polymerized PMMA did not significantly alter the hardness. Only the highest AI powder concentration, 2.5%, significantly reduced hardness. Incorporated AI might cause impurities that inhibit the polymerization reaction, increasing the quantity of residual monomers, which act as plasticizers.[31] AI powder concentrations higher than the material saturation limit could result in more impurities in the resin matrix, which may weaken the denture base and influence its surface properties. This might clarify that the maximum saturation between the PMMA matrix and AI powder occurred at a concentration of 2%. The present study results are in agreement with a previous study performed by Gad et al.[9] in which thymoquinone incorporated as an antifungal agent at a concentration of 1.5% or greater significantly affected the heat-polymerized denture base hardness, while lower concentrations had an insignificant effect.

Translucency is the ability of a material to enable light to pass through it and reflect back normal mucosal color.[32] The translucency of dental materials might be centered on the clinical appearance requirements of the patient. Consequently, dental practitioners should be very considerate regarding each material's optical properties. For instance, in cases of removable prosthesis fabrication, it is recommended to use a polymer that has superioresthetic properties.[33] The results of this study showed that all the modified groups had lower translucency than the control group; the higher the AI powder concentration, the lower the translucency.Shirkavand and Moslehifard[34] stated that to inhibit disarrangement of the diffused ultraviolet beam reflectance, it is important to avoid particle agglomeration within the matrix, as this agglomeration will reduce the material's translucency. The dissimilarity in optical properties arises from the difference in type and amount of fillers in the acrylic resin matrix. The dissimilarity in refractive indices between the fillers and the acrylic resin matrix affects the light reflection and refraction at the matrix and filler interface, which consequently affects the translucency of the material.[35] The passage of incident light is allowed through the material with interference between AI particles and the acrylic resin matrix. Due to the difference between the refractive indices of the AI particles (1.450–1.485) and the PMMA material (1.4813), the translucency is affected.[36] Therefore, translucency decreases as the concentration of the AI powder increases. The green color of the AI powder is also a contributing factor that negatively affects the translucency of the PMMA denture base material.

Table 1: ANOVA analysis results for all tested properties

Tested properties		*Sum of squares*	*df*	*Mean square*	*F*	*P value*
Flexural strength	Between groups	4739.723	5	947.945	344.296	0.000*
	Within groups	132.16	48	2.753		
	Total	4871.9	53			
Impact strength	Between groups	30.616	5	6.123	1.613	0.175
	Within groups	182.2	48	3.796		
	Total	212.82	53			
Surface roughness	Between groups	65.326	5	13.065	1.101	0.371
	Within groups	640.874	54	11.868		
	Total	706.200	59			
Hardness	Between groups	195.455	5	39.091	7.911	0.000*
	Within groups	266.831	54	4.941		
	Total	462.286	59			
Translucency	Between groups	805.970	5	161.194	202.060	0.000*
	Within groups	43.079	54	.798		
	Total	849.048	59			

Abbreviation: df, degrees of freedom;
*Statistically significant at 0.05 level of significance

AI is easy to handle, broadly available, and inexpensive. It has a significant antifungal effect in reducing the adhesion of *C. albicans*, so it could be utilized as a method for DIS prevention and treatment.[8] AI powder added to heat-polymerized PMMA denture base material caused an insignificant effect on the impact strength and surface roughness of all tested groups. However, flexural strength significantly decreased except for 0.5%AI group compared to the control group. Hardness had a significant decrease only at the highest concentration, 2.5%AI. However, translucency was significantly decreased in all of the tested concentrations. This reduction in translucency could be overcome by fabricating a denture base in two layers by adding a thin layer of PMMA or AI for the intaglio surface of the maxillary denture during processing or in the unesthetic area of the denture.[37] Moreover, AI powder can be incorporated into tissue conditioning and relining materials. AI powder could be added to heat-polymerized PMMA denture base material in low concentrations; 0.5%AI is the most appropriate concentration, as its effects on the mechanical, surface, and optical properties are within the acceptable threshold.

The limitations of the present study are the lack of aging procedures and natural saliva with pH and temperature alteration. In addition to one denture base material used for specimens, fabrication differs from the denture base configuration. Further investigations are required to evaluate the suggested techniques and the long-term antifungal activity of AI powder in a condition simulating the oral environment.

Table 2: Mean and standard deviation for heat polymerized specimens modified with different concentrations of AI

	AI concentrations Mean ± SD					
Tested properties	*Control*	*0.5%*	*1%*	*1.5%*	*2%*	*2.5%*
Flexural strength (MPa)	87.86 ± 1.76a,c,d,e,f	85.63 ± 1.18b,c,d,e,f	79.97 ± 1.75a,b,c,d,e,f	69.66 ± 1.41a,b,c,d,f	69.63 ± 1.47a,b,c,e,f	61.97 ± 2.20a,b,c,d,e,f
Impact strength (KJ/m2)	14.03 ± 2.17	12.39 ± 1.71	12.82 ± 1.52	12.97 ± 1.38	11.97 ± 2.90	11.74 ± 1.56
Ra (µm)	0.16 ± 0.04	0.17 ± 0.02	0.18 ± 0.01	0.18 ± 0.01	0.25 ± 0.02	0.26 ± 0.04
Hardness (VHN)	35.37 ± 1.89a	32.36 ± 2.19	34.40 ± 3.05b	33.78 ± 1.73c	32.63 ± 0.89	29.71 ± 2.86a,b,c
Translucency	21.01 ± 1.13a	19.60 ± 1.14a,b	19.31 ± 0.80a,c	17.63 ± 0.55a,b,c,d	14.70 ± 0.72a,b,c,d,e	10.16 ± 0.86a,b,c,d,e

Abbreviation: AI, *Azadirachta indica*; Ra, surface roughness; SD, standard deviation; Same alphabets showed significant results.
*p <0.05 was considered statistically significant

Conclusion

Within the limitations of the present analysis, it could be concluded that AI powder incorporated into heat-polymerized acrylic resin powder at a low concentration of 0.5% as an antifungal agent did not significantly alter the material's mechanical and surface properties. Although AI powder significantly decreased translucency, it can be used in low concentration as its effect is considered within the acceptable threshold. The present study builds on the previous investigations and contributes to establishing a denture base with antifungal activities and minimal adverse effects on denture properties.

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