# Effect of addition of silver nanoparticles on flexural and impact strength of heat cure acrylic resin

**Ranj A. Omer[(1)]; Fahd S. Ikram[(2)]**

***Background and objectives:*** Heat cure denture base material is the most commonly used material for fabrication of removable prosthesis since its introduction in 1937. The unresolved problem of frequent fracture is one of the main drawbacks when used in denture construction. The purpose of this study was to evaluate the influence of silver nanoparticles on flexural and impact strength of heat-polymerized resin.
***Materials and methods:*** Silver nanoparticles were impregnated at 1%, 3% and 5% by weight to the monomer of methyl methacrylate with the aid of probe sonicator. Afterward, they were mixed with the acrylic powder. Sixty samples were prepared in total to observe its influence on flexural and impact strength.
***Results:*** Flexural strength values revealed a statistically significant difference ($p<0.05$) among the three concentrations. The results indicated a 22% reduction in the mean value for 3% while 1% and 5% caused 20% and 21% decrease respectively when compared to control. Regarding impact test, it demonstrated a statistically significant difference only for 5% that caused a drastic drop in impact value by 41% in contrast to the control group.
***Conclusion:*** Within the limitations of this study, it can be concluded that the addition of silver nanoparticles caused a reduction in mechanical strength of heat cure acrylic except for 3% which caused a minor non-significant increase in impact strength. Considering the negative effect on mechanical strength and jeopardizing the aesthetic value for acrylic, it can't be considered as a suitable additive to enhance the properties tested.

***Keywords:*** Acrylic resin, silver nanoparticles, flexural strength, impact strength.

[(1)]B.D.S., Master student at the College of Dentistry, Hawler Medical University.
[(2)]B.D.S., M.Sc., Ph.D., Lecturer at the College of Dentistry, Hawler Medical University.

## Introduction

Complete and partial dentures that are made from acrylic considered the most popular method because it provides a much affordable option for reconstruction than other available prostheses.[1] Throughout the years, researchers are trying to improve the quality of biomaterials for fabrication of denture base together with the increase in life expectancy of human beings and increasing demand of patients for better aesthetics, function, and comfort.[2] Numerous materials with their modifications had been introduced to the market with enhanced mechanical and biological properties; despite this, there is still no single material that can fulfill the ideal requirement of denture base material.[3]
Polymethyl methacrylate (PMMA) is a derivative of acrylic acid, which is referred to as acrylic resin[4] introduced in 1937, by Walter Bauer, which gradually took the place of the traditional metal base and became the most widely used material in clinical practice[5,6] because of its good biocompatibility, dimensional stability, the absence of taste and odour, good tissue response and outstanding toxicity profile.[7] Despite those excellent properties, PMMA demonstrates high porosity[8] and frequent fracture under load due to fatigue and chemical degradation.[9, 10] Fracture resistance of PMMA does not show satisfactory results.[11] According to a survey done in 1981, 68% of dentures had broken within three years of their

construction.[12]

Due to their unsatisfactory properties, PMMA remains as an active material for research.[7] Generally speaking, there are three methods manufacture can use to enhance mechanical properties of denture base: discovery or development of new material to PMMA; chemical alteration of PMMA to fabricate high impact resin; and reinforcement of PMMA by other materials (e.g., nanoparticles).[13–15] Addition of nanoparticles (NPs) to the polymer matrix will result in alteration of mechanical properties by providing resistance against stress which may cause cracking.[14,17,18] Depending on the way the material was enhanced; it was based on the size, shape, type, and concentration of the added material.[18]

Alveolar ridge resorption is a continuous and irregular operation that causes uneven prosthesis support[19] with perpetual chewing cycles which will result in the generation of micro-cracks in the material and with the continual application of force will cause propagation of cracks and flexural fatigue that commonly manifest itself as midline fracture.[15, 20] Studies had tried to improve the flexural properties of the material to overcome the consequence of fracturing and enhancing patient's satisfaction.[21] In a study by Arora and his colleagues that added silver fillers at 25% to PMMA, the results showed a reduction in flexural mean when compared to control.[22] Following this, silver filler was impregnated to the same material and showed an increase in flexural strength for 10% and 20% while the 30% had a reverse effect.[23] Furthermore, AgNPs added at 0.3%, 0.8%, and 1.8% to heat-polymerized acrylic resin revealed a reduction in flexural value for all concentrations.[24] Munikamaiah et al. evaluated the flexural strength of PMMA that was reinforced with 0.5% and 5% AgNPs that was cured with two different curing cycles; results revealed an increase in the flexural mean by 7.5% and 4.4% respectively.[25] Moreover, the effect of 0.05% and 0.2% AgNPs on flexural strength of heat-polymerized acrylic resin was investigated by Oyar et al. where only low concentration showed an increase in the flexural strength of the acrylic.[26]

The second most common scenario that the denture experiences during their lifespan is when it falls and is exposed to a sudden impact. This is a common finding in clinical practice since removable prosthesis is usually used by geriatric patients.[25] Enhancing the impact strength of denture base is of great concern[27] with only a few studies available that evaluated the effect of silver particles on impact strength. In a study by Gaffariand and his colleagues[28] where they added AgNPs to acrylic, the results revealed a decrease in impact strength when added at 25% making it more susceptible to breakage by an impact force. While, in a recent study that impregnated the same filler at 0.3%, 0.8%, and 1.8% to heat-polymerized resin, it showed no effect on impact strength for all concentrations.[24] Finally, Oyar et al.[26] incorporated AgNPs into PMMA at two concentrations. The results recorded enhancement in impact strength at 0.05% while 0.2% had an opposite effect. This study was carried out to assess the impact of silver nanoparticles on flexural and impact strength of heat cure PMMA to discover a material that can stay in service to the desired time without a need for repair.

**Materials and Methods**

Considering the addition of NPs into acrylic resin polymers is to enhance its properties, this has been gained by using low filler content between 1% to 5%[29] because increasing the content above this level can have a significant impact on mechanical properties.[17] As a result, AgNPs were added at 1%, 3% and 5% by weight to heat polymerized polymer.

The NPs used in the study was bought from Richest Group Company in China with 50nm in size and were treated with a saline coupling agent. The saline agent will provide a better bond between particles and acrylic[30] and minimizes agglomeration.[18, 31] To reduce agglomeration of NPs, they were added to acrylic monomer first and then mixed with powder[24,26,30] with the aid of probe sonicator (Biosafer 900-02). According to a pilot study that was performed, the below setting was chosen:

Power Rate: 80%
Power: 900w
Probe size: 12 F
Processing time: 1-minute
Pulse on: 8s

Pulse off: 2s
Temperature warning: 37 °C.
Sonication was started with 8s on and 3s off to keep the temperature within the set range. After the sonication time was over, polymer powder was added immediately to the suspension (within 10s) to prevent re-agglomeration of NPs.[17] The mix was polymerized using conventional flasking and pressure packing technique. After the polymerization was over, de-flasking was done, and samples with gross porosity were excluded according to revised ADA specification number 12 for denture base polymer.[32]

**Flexural strength test.** For flexure strength test 5 samples were prepared for each concentration of AgNPs, making a total of 20 samples, including the unmodified group. Each sample had a dimension of 65 mm length x 10mm width x 3mm thickness and was stored in distilled water at 37 ± 1 °C for 50 ± 2 hours, in compliance with International Standard Organization (ISO) 1567:1999 Denture Base Polymers.[33] The flexural value was obtained by doing a three-point bending test using a universal testing machine. The samples were placed on circular supports (3.2mm in diameter and 10.5mm in length) that are 50 mm apart (Figure 1). Then force was applied perpendicular to the center of the specimen using the loading nose at a cross-head speed of 5.00 ± 1 mm/ min until it breaks.[33] The maximum load required to fracture the specimen was recorded.

The flexural strength was calculated using the formula:[33]

Where: F: is the maximum load, in Newton, exerted on the specimen; l: is the distance, in millimeter, between the supports, accurate to ±0.01; b: is the width, in millimetre, of the specimen measured immediately prior to water storage where h: is the height, in millimeter, of the specimen measured immediately prior to water storage.

**Impact strength test.** For this test, ten samples for each concentration were prepared to make a total of 40 samples, including the control group. The samples had dimensions of 80 ± 2 x 10 ± 0.2 x 4 ± 0.2 mm according to ISO 179-1: 2010 (34) and were conditioned for 16 hours at 23 ± 2 °C and 50 ± 5 % relative humidity according to ISO 291:2008.[35]

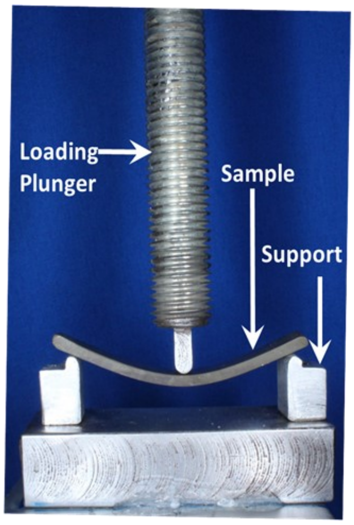


**Figure 1: Bending the sample using universal testing machine**

A Charpy type of digital impact tester (Figure 2) was used to determine the impact strength. A pendulum of one joule was installed on the impact tester. Before starting the procedure, a test was performed without the sample to check for air friction. The air friction value was subtracted from the impact strength value for each sample. The procedure was followed according to ISO 179-1:2010 for the unnotched specimen.[34]

After the samples were fractured, the Charpy's impact strength for unnotched specimens was calculated in $KJ/m^2$ using the

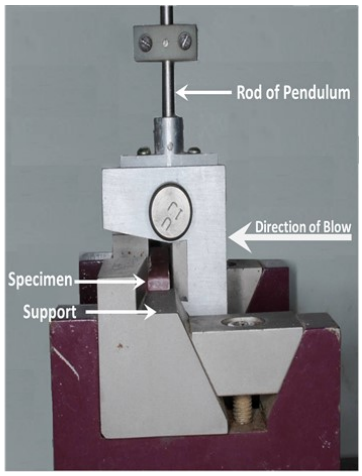


**Figure 2: Charpy type digital impact tester used in the study**

formula: $a_{cU} = \frac{E_C}{h.b} x\ 10^3$ [34]

Where: *Ec* is the corrected energy, in joules, absorbed by breaking the test specimen; *h* is the thickness, in millimetres, of the test specimen and *b* is the width, in millimetres, of the test specimen.

Statistical Package for Social Sciences (SPSS, version 23) was used for data analysis and entry. One-way ANOVA with Tukey's Honest Significant Difference (HSD) was performed to determine if there is a statistically significant difference between each concentration of AgNPs when compared to control. For statistical analysis, significant level $\alpha = 0.05$ was considered.

**Results**

The data that was obtained from flexural and impact strength test were calculated using one way ANOVA with HSD to find out the effect of addition of NPs at the three concentrations (1, 3, and 5%) The flexural strength results revealed statistically significant differences ($p< 0.05$) between each concentration of AgNPs in reference to control. The results indicate 20%, 22% and 21% reduction in mean value for 1%, 3% and 5% AgNPs respectively. Despite the reduction in strength value for all concentrations but none of them compromised the strength beyond the minimal flexural strength value (65 MPa) that is set for Type 1 denture base polymer.[33] Table 1 and Figure 3 illustrates the mean flexural strength value. As can be seen from the table, the highest mean 87.205 MPa, which was recorded for the control group.

Regarding the impact strength test, it demonstrated statistically significant difference only for 5% that caused a drastic drop

**Table 1: Descriptive statistics and multiple comparisons of each concentration of AgNPs with a control group for flexural strength**

| Nanoparticle | Concentration % | Mean (MPa) | SD | ANOVA P-value of concentration with control |
|---|---|---|---|---|
| Silver | 1 | 69.669 | 2.486 | 0.00 |
| | 3 | 68.447 | 2.410 | 0.00 |
| | 5 | 69.329 | 3.065 | 0.00 |
| Control | | 87.205 | 2.499 | |

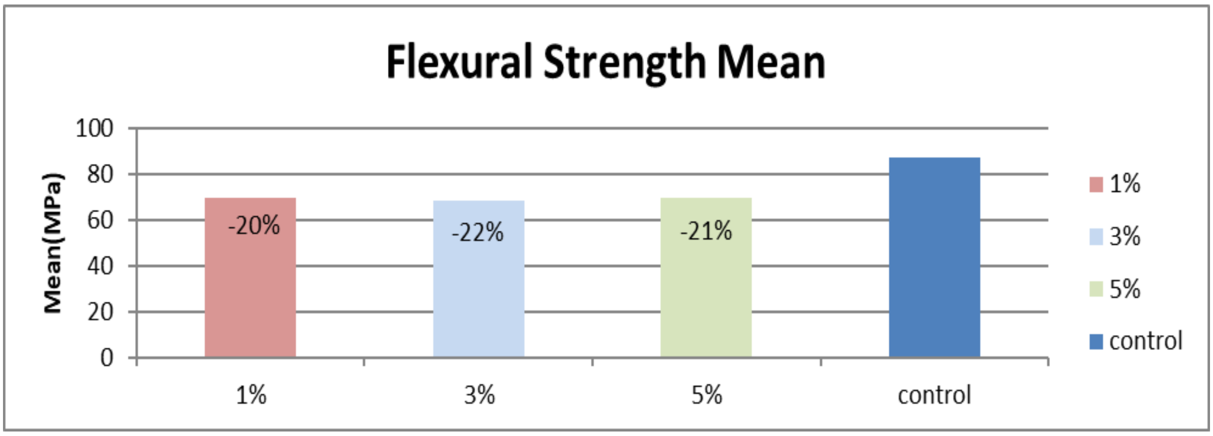


**Figure 3: Flexural strength mean for AgNPs concentration for heat cure acrylic**

in impact value by 41% in contrast to control. Also, the negative effect of 1% AgNPs on the impact strength was observed, which caused 0.8% reduction; while 3% AgNPs showed a non-significant increase in impact strength. Table 2 and Figure 4 shows the summary for impact values where the highest mean value was for 3% (24.733 $KJ/m^2$) while 5% (14.190) showed the lowest value among the group.

## Discussion

PMMA has been considered as the main material for denture base fabrication due to its pleasing appearance, good tissue response, and ease of manipulation,[36] but it is mechanical properties not satisfactory.[37] This reflects the high percentage of denture fracture that has been reported in the literature which compromises the longevity of the prosthesis.[38]

**Table 2: Descriptive statistics and multiple comparisons of each concentration of AgNPs with a control group for impact strength.**

| Nanoparticle | Concentration (%) | Mean $KJ/m^2$ | SD | ANOVA P value of concentration with control |
|---|---|---|---|---|
| Silver | 1 | 23.885 | 1.031 | 0.998 |
| | 3 | 24.733 | 2.914 | 0.935 |
| | 5 | 14.190 | 3.111 | 0.000 |
| Control | | 24.073 | 2.409 | |

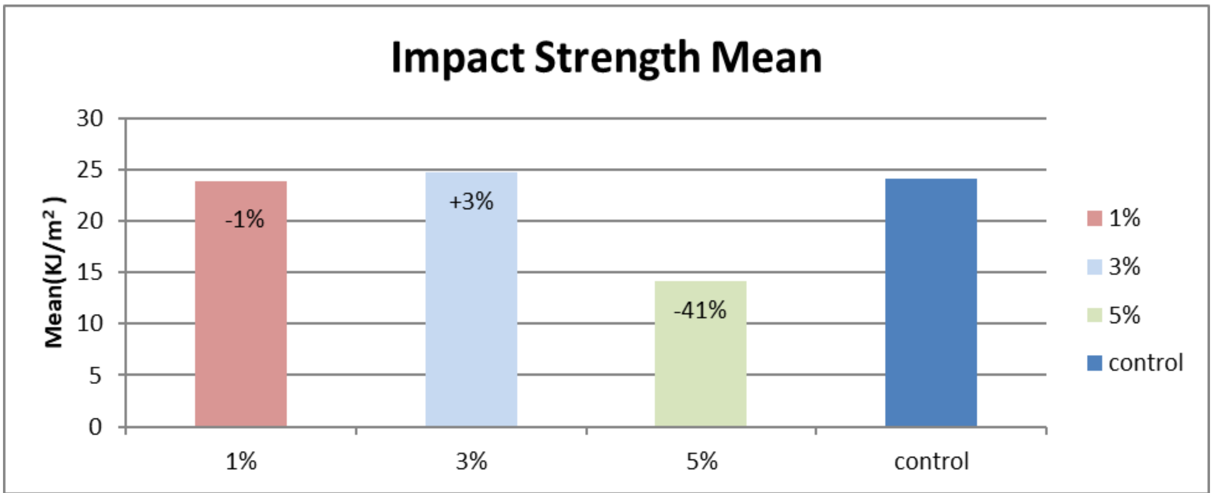


**Figure 4: Impact strength mean for AgNPs concentration for heat cure acrylic**

The masticatory process will result in movement and distortion of the denture, in turn, will impact on supporting tissue and the denture itself.[39] The denture base is subjected to different types of stress in the mouth.[40] Flexural fatigue from intraoral forces and extraoral impact are the two most common culprits responsible for fracturing dentures.[41] As a result, impact and flexural strength test were conducted to closely resemble clinical conditions the removable prosthesis goes through during their functional use.

The results for this study showed when AgNPs were dispersed in acrylic at 1%, 3% and 5% causing a drastic reduction in flexural strength by 20%, 22%, and 21% respectively. The findings were in agreement with Arora et al.'s[24] and Köroğlu et al.'s[26] research were a reduction was displayed in flexural value for different concentrations of silver. This can be correlated to less silver content per unit area of the matrix of

PMMA which induces moister incorporation.[22] This backs up the study that was performed by Yadav et al. that added 10% and 20% silver and resulted in an increase in flexural value.[23] Regarding impact strength, 5% silver caused a 41% reduction in impact value that was statistically significant at p (0.00< 0.05).

As can be seen, the concentration of the NPs certainly played a significant role in compromising the mechanical strength of acrylic. This turn is in agreement with Gaffariand et al.'s research[28] that revealed a reduction in strength with an increasing concentration of NPs. Also, other researches[42,43] had determined an inverse relationship between the increase in NPs concentration and strength.

There are several concepts regarding this inverse relation. Dispersion of NPs which had shown to play an important role in reinforcing the material. Such as increasing in filler content in addition to poor dispersion will result in suspending resin matrix continuity and creating a defect in the material which weakens it in the outcome .[44] Improper dispersion of NPs will also interfere with the reaction of methyl methacrylate, which causes an increase in uncreative monomer that behaves as a plasticizer.[45,46] The plasticizer capable of getting into polymer chains which induce the separate chains to become more tenuous and reduce the attraction force between molecules, as a consequence the acrylic will be more flexible but brittle.[47] In addition to this, NPs might have acted as impurities within the PMMA which led to an unfavorable decrease in mechanical strength.[24,28] The most probable cause of reduction for the mechanical strength of resin could be attributed to the low concentration of filler which results in poor interaction between PMMA and AgNPs.[48] It is a well-known fact that NPs lacks chemical bond that results in poor adhesion between the particle and acrylic resin.[26,48] Agglomeration within the matrix will result in a reduction in strength[48] since too many fillers will act as a stress concentrating point[48,49,50,51] that will change the modulus of elasticity of the resin and mode of crack propagation through the polymerized specimen and also perform as an interfering factor in the integrity of polymer matrix.[52] Furthermore, agglomeration will bring about micro-cracks and micro-pores as a structural defect which endangers mechanical properties of the polymer.[45]

## Conclusion

Within the limitations of this *in vitro* study, it can be concluded that the addition of silver nanoparticles caused a reduction in mechanical strength of heat cure acrylic except for 3% which caused a minor non-significant increase in impact strength only. Considering it is negative effect on mechanical strength and jeopardizing the aesthetic value for acrylic in the result, it won't be a suitable additive to enhance the properties tested.

## Conflicts of interest

The author reported no conflict of interests.

## References


1. Campbell SD, Cooper L, Craddock H, Hyde TP, Nattress B, Pavitt SH, et al. Removable partial dentures: The clinical need for innovation. The Journal of Prosthetic Dentistry. 2017; 118(3):273-80
2. Alla R, Raghavendra KN, Vyas R, Konakanchi A. Conventional and contemporary polymers for the fabrication of denture prosthesis: part I–overview, composition and properties. Int J Appl Dent Sci. 2015; 1(4):82–89.
3. Arora S, Khindaria SK, Garg S, Mittal S. Comparative evaluation of linear dimensional changes of four commercially available heat cure acrylic resins. Contemporary clinical dentistry. 2011;2 (3):182.
4. Raghdaa KJ, Ali AM. Evaluation and comparison of the effect of repeated microwave irradiations on some mechanical and physical properties of heat cure acrylic resin and valplast (nylon) denture base materials. Journal of baghdad college of dentistry. 2011;23(3):6–10.
5. Yli-Urpo A, Lappalainen R, Huuskonen O. Frequency of damage to and need for repairs of removable dentures. Proceedings of the Finnish Dental Society Suomen Hammaslaakariseuran toimituksia. 1985;81(3):151.
6. Kim YK, Grandini S, Ames JM, Gu L, Kim SK, Pashley DH, et al. Critical review on methacrylate resin–based root canal sealers. Journal of Endodon-

tics. 2010;36(3):383–399.
7. Spasojevic P, Zrilic M, Panic V, Stamenkovic D, Seslija S, Velickovic S. The mechanical properties of a poly (methyl methacrylate) denture base material modified with dimethyl itaconate and di-n-butyl itaconate. International Journal of Polymer Science. 2015;2015:1-9.
8. Price CA. A history of dental polymers. Australian prosthodontic journal. 1994; 8:47–54.
9. Jagger DC, Harrison A, Jandt KD. The reinforcement of dentures. Journal of Oral Rehabilitation. 1999;26(3):185–194.
10. Vivek R, Soni R. Denture base materials: Some relevant properties and their determination. Int J Dent Oral Health. 2015;1(4):1–3.
11. Nejatian T, Sefat F, Johnson T. Impact of Packing and Processing Technique on Mechanical Properties of Acrylic Denture Base Materials. Materials. 2015;24;8(5):2093–109.
12. Nejatian T, Johnson A, Van Noort R. Reinforcement of denture base resin. In: Advances in Science and Technology. Trans Tech Publ; 2006: 124–129.
13. Hamedi-Rad F, Ghaffari T, Rezaii F, Ramazani A. Effect of nanosilver on thermal and mechanical properties of acrylic base complete dentures. Journal of dentistry (Tehran University of Medical Sciences). 2014;11(5):495–505.
14. Alla RK, Sajjan S, Alluri VR, Ginjupalli K, Upadhya N. Influence of fiber reinforcement on the properties of denture base resins. Journal of Biomaterials and Nanobiotechnology. 2013;4(1):91–7.
15. Arıkan A, Ozkan YK, Arda T, Akalın B. Effect of 180 days of water storage on the transverse strength of acetal resin denture base material. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2010;19(1):47–51.
16. TAHEREH Ghafari, Hamedi RF, EZZATI B. Does addition of silver nanoparticles to denture base resin increase its thermal conductivity? 2014;32(3):139-144.
17. Alnamel HA, Mudhaffer M. The effect of Silicon di oxide Nano-Fillers reinforcement on some properties of heat cure polymethyl methacrylate denture base material. Journal of baghdad college of dentistry. 2014;26(1):32–36.
18. Gad M, ArRejaie AS, Abdel-Halim MS, Rahoma A. The Reinforcement Effect of Nano-Zirconia on the Transverse Strength of Repaired Acrylic Denture Base. International Journal of Dentistry. 2016;2016:1–6.
19. Ajaj-ALKordy NM, Alsaadi MH. Elastic modulus and flexural strength comparisons of high-impact and traditional denture base acrylic resins. The Saudi dental journal. 2014;26(1):15–18.
20. Venkat R, Gopichander N, Vasantakumar M. Comprehensive analysis of repair/reinforcement materials for polymethyl methacrylate denture bases: mechanical and dimensional stability characteristics. The Journal of Indian Prosthodontic Society. 2013;13(4):439–49.
21. Kanie T, Arikawa H, Fujii K, Ban S. Impact strength of acrylic denture base resin reinforced with woven glass fiber. Dental materials journal. 2003;22(1):30–8.
22. Arora N, Jain V, Chawla A, Mathur VP. Effect of addition of sapphire (Aluminum oxide) or silver fillers on the flexural strength, thermal diffusivity and water sorption of heat-polymerized acrylic resins. Int J Prosthodont Restorat Dent. 2011;1(1):21–27.
23. Yadav P, Mittal R, Sood VK, Garg R. Effect of Incorporation of Silane-Treated Silver and Aluminum Microparticles on Strength and Thermal Conductivity of PMMA. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2012;21(7):546–551.
24. Köroğlu A, ŞAHİN O, KÜRKÇÜOĞLU I, DEDE DÖ, ÖZDEMİR T, Hazer B. Silver nanoparticle incorporation effect on mechanical and thermal properties of denture base acrylic resins. Journal of Applied Oral Science. 2016;24(6):590–596.
25. Munikamaiah RL, Jain SK, Pal KS, Gaikwad A. Evaluation of Flexural Strength of Polymethyl Methacrylate modified with Silver Colloidal Nanoparticles subjected to Two Different Curing Cycles: An in vitro Study. The journal of contemporary dental practice. 2018;19(3):262–268.
26. Oyar P, Asghari Sana F, Durkan R. Comparison of mechanical properties of heat-polymerized acrylic resin with silver nanoparticles added at different concentrations and sizes. Journal of Applied Polymer Science. 2018;135(6):45807.
27. Uzun G, Hersek N, Tincer T. Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resin. The Journal of prosthetic dentistry. 1999;81(5):616–620.
28. Ghaffari T, Hamedirad F, Ezzati B. In Vitro Comparison of Compressive and Tensile Strengths ofAcrylic Resins Reinforced by Silver Nanoparticles at 2% and0. 2% Concentrations. Journal of dental research, dental clinics, dental prospects. 2014;8(4):204.
29. Cevik P, Yildirim-Bicer AZ. The effect of silica and prepolymer nanoparticles on the mechanical properties of denture base acrylic resin. Journal of Prosthodontics. 2016;1–8.
30. Salahuddin N, El-Kemary M, Ibrahim E. Reinforcement of polymethyl methacrylate denture base resin with ZnO nanostructures. International Journal of Applied Ceramic Technology. 2018;15

(2):448–459.
31. Kassaee MZ, Akhavan A, Sheikh N, Sodagar A. Antibacterial effects of a new dental acrylic resin containing silver nanoparticles. Journal of applied polymer science. 2008;110(3):1699–1703.
32. Revised American Dental Association specification No. 12 for denture base polymers. The Journal of the American Dental Association. 1975;90 (2):451–458.
33. ISO 1567:1999 Denture Base Polymers.
34. British Standards Institution. Plastics - determination of charpy impact properties. non-instrumented impact test (ISO 179-1:2010). Part 1 Part 1. London: British Standards Institution; 2010.
35. ISO 291:2008 Plastics - Standard atmospheres for conditioning and testing.
36. Jagger DC, Harrison A, Jandt KD. The reinforcement of dentures. Journal of oral rehabilitation. 1999;26(3):185–194.
37. Kawaguchi T, Lassila LV, Sasaki H, Takahashi Y, Vallittu PK. Effect of heat treatment of polymethyl methacrylate powder on mechanical properties of denture base resin. Journal of the mechanical behavior of biomedical materials. 2014; 39:73–78.
38. Ahmed MA, Ebrahim MI. Effect of Zirconium Oxide Nano-Fillers Addition on the Flexural Strength, Fracture Toughness, and Hardness of Heat-Polymerized Acrylic Resin. World Journal of Nano Science and Engineering. 2014;4(2):50–7.
39. Beyli MS, Von Fraunhofer JA. An analysis of causes of fracture of acrylic resin dentures. Journal of Prosthetic Dentistry. 1981;46(3):238–241.
40. Stafford GD, Huggett R, Causton BE. Fracture toughness of denture base acrylics. Journal of biomedical materials research. 1980;14(4):359–371.
41. Hashem M, Alsaleem SO, Assery MK, Abdeslam EB, Vellappally S, Anil S. A comparative study of the mechanical properties of the light-cure and conventional denture base resins. Oral Health Dent Manag. 2014;13(2):311–5.
42. Ihab NS. Evaluation the effect of modified nanofillers addition on some properties of heat cured acrylic denture base material. Journal of Baghdad college of dentistry. 2011;23(3):23–29.
43. Hameed HK, Rahman HA. The effect of addition nano particle ZrO2 on some properties of autoclave processed heat cure acrylic denture base material. Journal of baghdad college of dentistry. 2015;27(1):32–39.
44. Asopa V, Suresh S, Khandelwal M, Sharma V, Asopa SS, Kaira LS. A comparative evaluation of properties of zirconia reinforced high impact acrylic resin with that of high impact acrylic resin. The Saudi Journal for Dental Research. 2015 Jul;6 (2):146–51.
45. Shirkavand S, Moslehifard E. Effect of TiO2 nanoparticles on tensile strength of dental acrylic resins. Journal of dental research, dental clinics, dental prospects. 2014;8(4):197.
46. Nazirkar G, Bhanushali S, Singh S, Pattanaik B, Raj N. Effect of Anatase Titanium Dioxide Nanoparticles on the Flexural Strength of Heat Cured Poly Methyl Methacrylate Resins: An In-Vitro Study. The Journal of Indian Prosthodontic Society. 2014 Dec;14(S1):144–9.
47. Tandra E, Wahyuningtyas E, Sugiatno E. The effect of nanoparticles TiO2 on the flexural strength of acrylic resin denture plate. Padjadjaran Journal of Dentistry. 2018;30(1).
48. Sodagar A, Bahador A, Khalil S, Saffar Shahroudi A, Zaman Kassaee M. The effect of TiO2 and SiO2 nanoparticles on flexural strength of poly (methyl methacrylate) acrylic resins. Journal of Prosthodontic Research. 2013 Jan;57(1):15–9.
49. Nejatian T, Johnson A, Van Noort R. Reinforcement of denture base resin. In: Advances in Science and Technology [Internet]. Trans Tech Publ; 2006. p. 124–129. Available from: https://www.scientific.net/AST.49.124
50. Kul E, Aladağ Lİ, Yesildal R. Evaluation of thermal conductivity and flexural strength properties of poly (methyl methacrylate) denture base material reinforced with different fillers. The Journal of prosthetic dentistry. 2016;116(5):803–810.
51. Chladek G, Basa K, Mertas A, Pakie\la W, Żmudzki J, Bobela E, et al. Effect of Storage in Distilled Water for Three Months on the Antimicrobial Properties of Poly (methyl methacrylate) Denture Base Material Doped with Inorganic Filler. Materials. 2016;9(5):328.
52. Vojdani M, Bagheri R, Khaledi AAR. Effects of aluminum oxide addition on the flexural strength, surface hardness, and roughness of heat-polymerized acrylic resin. Journal of dental sciences. 2012;7(3):238–244.