The Effect of Nano- ZrO_2 and nano-Al_2O_3 Reinforcement on Flexural and Impact Strength of Repaired Acrylic Denture Base

Yasmeen F. Al-Mahdy[1] and Heba E. Eltayeb[2]

ABSTRACT

Purpose: This study was conducted to evaluate the effect of reinforcement of different concentrations of nano-ZrO_2 and nano-Al_2O_3 on the flexural strength and impact strength of repaired acrylic resin denture bases. **Materials and Methods:** A total of 100 specimens were prepared from heat-polymerized acrylic resin and then they were equally divided for the flexural and impact strength tests. 50 specimens were assigned for each testing group. For the flexural strength testing, metallic rectangular molds with rectangular-shaped (65 mm length x10 mm width x 2.5 mm thickness) were prepared. While specimens for the impact strength testing were prepared using rectangular-shaped molds with dimensions of (50 mm length x6mm width x4mm thickness). The prepared intact specimens were cut vertically in two halves along their long axis. For the flexural and impact strength testing, a repair gap was done. Specimens for each strength test were divided into one control group (specimen repaired with autopolymerizing acrylic resin with no fillers) and two repair groups with 2 concentrations (2% and 5%) of nano-ZrO_2 fillers and two repair groups with 2 concentrations (2% and 5%) of nano-Al_2O_3 fillers. Flexural strength was measured using an Instron mechanical testing machine and impact strength was measured by Izod impact tester. **Results:** For the flexural strength results, the highest flexural strength was recorded with the 5% nano-ZrO_2 fillers repair group followed by the 2% nano-ZrO_2 group which also recorded higher significant mean value than the control group. In both nano-Al_2O_3 groups, there was a highly significant reduction in the flexural strength for both concentrations. For the impact strength results, the highest impact strength was recorded for the 2% nanoZrO$_2$ fillers repair group followed by the 5% nano-ZrO_2 group which also recorded higher significant mean values than the control group. In the 2% nano-Al_2O_3 repair group, there was a non-significant difference in the impact strength mean values compared with the control group. While the repair group reinforced with 5% nano-Al_2O_3 showed significant reduction in impact strength. **Conclusions:** The incorporation of nano-ZrO_2 into repair resins may improve the flexural and impact strength of the repaired denture base whereas nano-Al_2O_3 caused reduction of both strengths.

KEYWORDS

Denture repair, nanofillers, nano-ZrO2, nano-Al2O3, flexural strength, impact strength.

---

1. Assistant Professor of Removable Prosthodontics, Faculty of Dental Medicine for Girls, Al-Azhar University
2. Lecturer of Dental Biomaterials, Faculty of Dental Medicine for Girls, Al-Azhar University

INTRODUCTION

Although different materials have been used for denture base materials, polymethyl methacrylate (PMMA) has been extensively used for 80 years now. PMMA has the advantages of ease of manipulation and repair, accurate fit, ease of polishing, esthetic appearance, and stability in the oral environment [1,2,3], However, PMMA also has several disadvantages, including allergic reactions to the residual monomer, insufficient surface hardness, poor wear resistance, and polymerization shrinkage [1,4,5].

Additionally, PMMA has a major drawback which is its low transverse and impact strength that leads to fracture of prosthesis [6,7]. Increase in impact strength is required to prevent the fracture of denture resulting from its accidental fall, while transverse strength helps to withstand higher flexural stresses developed during mastication[6,7,8,9] . Denture base materials are subjected to compressive, tensile, and shear stresses during function, and fractures in the denture base may develop through repeated masticatory forces or high impact forces that may occur as a result of dropping the prosthesis [2,10].

The fracture of acrylic resin prosthesis is a common clinical incidence, the prosthesis may fracture accidentally due to an impact outside the mouth or it may fracture while in service in the mouth. This type of fracture occurs near or close to midline and it occurs more often in maxillary than in mandibular denture [7,11]. Fracture inside the mouth is generally the result of poor fit of denture base, improper occlusal plane, lack of balanced occlusion , problems in the design and manufacturing of the denture as well as fatigue failure caused by repeated flexure over a period of time[7,12,13,14] , while fractures outside the mouth could be due to expelling the denture from the mouth while coughing, or simply dropping it[12,14,15,16] .

Fracture of denture base in the mouth occurs via fatigue mechanism in which, over a period of time, even the relatively small flexural stresses lead to the formation of microscopic cracks in areas of stress concentration. With continued load bearing, these cracks fuse to ever growing fissure that weakens the material. Catastrophic failure results from a final loading cycle that exceeds mechanical capacity of remaining sound portion of the material. Additionally, denture fracture is also frequently related to faulty design, fabrication and material choice [17]. Moreover, the most common location for fracture of the repaired specimens is at the junction of the old and new materials rather than through the center of the repair where the load is applied. Therefore, it was clearly indicated that the interface of the old and new materials is the location of stress concentration during transverse strength testing, regardless of the technique used [18].

Amongst various methods proposed for repairing fractured denture bases, use of auto-polymerized acrylic resins, which generally allows a simple and quick repair, is considered the most popular method[16]. Although Heat-polymerized materials have been proven to have superior mechanical properties, compared to auto-polymerized materials[19], but its use in repair is associated with the risk of denture distortion or warpage due to reheating[12]. Thus, autopolymerizing resin has gained more popularity due to its easy handling, saving chairside time; moreover, the patient spends less time without denture during the repair process [20,21].

Different materials have been used to Repair and reinforce polymethyl methacrylate (PMMA) resin denture base aiming to improve mechanical properties of denture base, which include stainless steel alloy wires[22,23] , polyethylene fibers[24,25], glass fibers [26,27], carbon fibers[28] , polyaramid fibers[29] , autopolymerizing acrylic resin, heat-cure acrylic resin, visible light-polymerized resin, microwave polymerized acrylic resin. The material to be used for the repair of denture base depends on the working time of the material, the strength to be attained, and the dimensional stability achieved during and after repair [30,31].

It was believed that the incorporation of the nano-fillers to the polymer matrix enhances the mechanical properties of the resulted resin composite. This would be influenced by the ratio, adhesion between the polymer matrix and the fillers, configuration and structure and finally the chemical constituent of those fillers [32]. Zirconia (ZrO_2) is one of the biocompatible dental ceramic materials that improved the mechanical properties especially the fracture resistance and has been widely used because it possesses high mechanical strength, good surface properties, and good biocompatibility and biological properties, thus making it a beneficial material for use in dental materials, such as reinforcement of denture bases and repair[33-35]. The incorporation of zirconia nanoparticles nano-ZrO_2 into PMMA has been suggested to improve PMMA properties [36,37] such as flexural strength and impact strength. Also, the effect of alumina (Al_2O_3) addition has been reviewed and reported a positive impact on the properties of acrylic resin[38]. Although flexural stresses that are counteracted by the flexural strength of the material are a constant phenomenon during mastication, impact strength is also required to prevent fracture upon accidental dropping or falling of the dentures[39].

This study was conducted to evaluate the effect of reinforcement of different concentrations of nano-ZrO_2 and nano-Al_2O_3 on the flexural strength and impact strength of repaired acrylic resin denture bases. The null hypothesis is that the addition of different concentrations of nano-ZrO_2 and nano-Al_2O_3 will not improve the flexural strength and impact strength of repaired PMMA denture bases.

MATERIALS AND METHODS

Specimens preparation

This in-vitro study was conducted at the Faculty of Dental Medicine (Girls' branch), Al-Azhar University. A total of 100 specimens were prepared from heat-polymerized acrylic resin (Vertex heat-Curing acrylics, Vertex Dental, Netherlands) and then they were equally divided for the flexural and impact strength tests. 50 specimens were assigned for each testing group. For the flexural strength testing, Metallic rectangular flasks with rectangular-shaped molds (65 mm length x10 mm width x 2.5 mm thickness) following the ISO/DIS 1567 international standard were used to prepare 50 specimens. While specimens for the impact strength testing were prepared using rectangular-shaped molds with dimensions of (50mm length x6mm width x4mm thickness) following the ISO standard 1567:1999/Amd.1:2003(E) using Izod pendulum impact testing machine. Each specimen was fabricated with a V-shaped notch. The notch depth was 0.8 mm across the entire 6 mm width of the specimen, leaving an effective depth of 3.2 mm below the notch. The force was applied to the notched surface [40].

All flasks were surrounded with rubber to prevent water entry during curing. The resin was manipulated, packed, pressed into the mold according to the manufacturer's instructions and processed by the conventional heat curing method used for denture processing. The specimens were all finished and polished using burs, abrasive paper and pumice as routinely used in conventional denture construction. The polished specimens were given identifying numbers. The specimens were then measured with a digital caliper and the dimensions were recorded then immersed in water at 50°C for 1h for removal of excess residual monomer and then stored in water at room temperature.

The prepared intact specimens were cut vertically in half along their long axis by a high-speed diamond disk cutter under copious irrigation. For the flexural strength specimens, 2.5 mm was marked on the right and left from the center line on the top to create a repair gap of 5 mm on the top, and 1.25 mm was marked on the right and left from the center line at the bottom to create a repair gap of 2.5mm in the bottom. For the impact strength

specimens, 5 mm was marked on the right and left from the center line on the top to create a repair gap of 10 mm on the top, and 1.25 mm was marked on the right and left from the center line at the bottom to create a repair gap of 2.5mm in the bottom (Figure 1 a,b). The prepared intact specimens were then cut in accordance with the markings on the specimen until a 45° bevel joint was created between the two pieces. To standardize the 45° bevel joints, a digital caliper was used to evaluate pairs of repair group specimens according to the required dimensions.

Sample grouping:

Specimens for each strength test were divided into one control group (specimen repaired with autopolymerizing acrylic resin with no fillers) and two repair groups with 2 concentrations of nanoZrO$_2$ fillers and two repair groups with 2 concentrations of nano Al$_2$O$_3$ fillers as shown in table 1.

The metal molds that were used to fabricate the intact specimens were re-used to hold the reassembled specimens for repair.
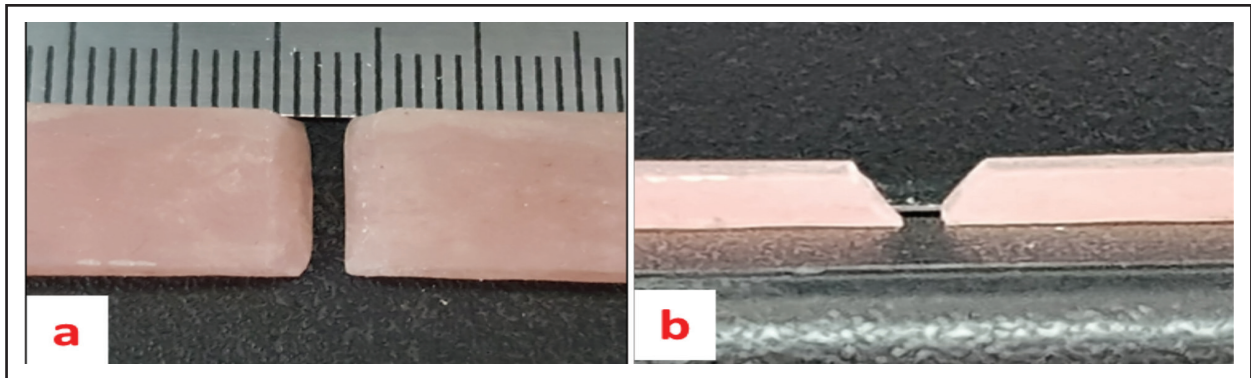

Fig. (1) Repair gaps of specimens. a: flexural strength specimen, b: impact strength specimen

Table (1) *Specimen grouping with codes:*

Strength testing	Group	Code	Repair material
Flexural strength testing	control	CF	Unreinforced autopolymerized acrylic resin for flexural strength testing
	nano-ZrO$_2$	2ZrF	Repaired with autopolymerizing acrylic resin reinforced with 2 wt% of nano-ZrO$_2$ for flexural strength testing
		5ZrF	Repaired with autopolymerizing acrylic resin reinforced with 5 wt% of nano-ZrO$_2$ for flexural strength testing
	nano-Al$_2$O$_3$	2AlF	Repaired with autopolymerizing acrylic resin reinforced with 2 wt% of nano-Al$_2$O$_3$ for flexural strength testing
		5AlF	Repaired with autopolymerizing acrylic resin reinforced with 5 wt% of nano-Al$_2$O$_3$ for flexural strength testing
Impact strength testing	control	CI	Unreinforced autopolymerized acrylic resin for impact strength testing
	nano-ZrO$_2$	2ZrI	Repaired with autopolymerizing acrylic resin reinforced with 2 wt% of nano-ZrO$_2$ for impact strength testing
		5ZrI	Repaired with autopolymerizing acrylic resin reinforced with 5 wt% of nano-ZrO$_2$ for impact strength testing
	nano-Al$_2$O$_3$	2AlI	Repaired with autopolymerizing acrylic resin reinforced with 2 wt% of nano-Al$_2$O$_3$ for impact strength testing
		5AlI	Repaired with autopolymerizing acrylic resin reinforced with 5 wt% of nano-Al$_2$O$_3$ for impact strength testing

Specimens preparation:

i- Silanization of nano-ZrO₂ and nano- Al₂O₃ particles:

Both nano-fillers were silanized separately by the same procedure as follows; Silane coupling agent TMSPM (3-(Trimethoxysilyl)propyl methacrylate, SIGMA-ALDRICH, Germany) was added to nano-filler particles of 99.5% purity (Nano-tech Egypt for photo electronics, city of 6th October ,Egypt) resulted in the creation of reactive groups on its surface, which allows for adequate adhesion between nanoparticles and the resin matrix. To achieve this, TMSPM was dissolved in acetone to ensure that it would evenly coat the surfaces of the nano-filler particles. Filler particles were added to the TMSPM/acetone solution and stirred with a magnetic stirrer for 60 min. Then, a rotary evaporator was used to remove the solvent under vacuum at 60°C and 150 rpm for 30 min. When the sample was dried, it was heated at 120°C for 2 h and naturally cooled to obtain the surface-treated nano-filler [41].

ii- Nano-fillers incorporation to repair resin:

According to the group sampling, the silanized nano-ZrO₂ powder and nano- Al₂O₃ powder was incorporated to the autopolymerizing acrylic repair resin (Vertex Self-Curing, Vertex Dental, Netherlands) separately with the same procedure. Nano-filler and PMMA were pre-weighed using an electronic balance so that the nano-filler concentration was 2% and 5% by weight. Pre-weighed nano-filler powder were separately added to the autopolymerized acrylic resin powder and thoroughly mixed using a mortar and pestle to achieve an equal distribution of particles. The repair surfaces were first treated with the methyl methacrylate monomer for three minutes. Specimens were then placed into the mold and fixed to preserve the required repair gap. Then the polymer with nano-fillers was mixed with the monomer with a powder/liquid ratio of 2.5:1 and packed with slightly overfilling the repair gap to compensate for polymerization shrinkage. The molds holding the repaired specimens were placed into a pressure pot at a temperature of 37°C and subjected to 30 psi pressure for 30 min. Afterwards, specimens were inspected for any irregularity. Faulty specimens were discarded and final specimens were selected for each group. Resin specimens were finished, polished, and then put into distilled water and stored at 37°C for 48 hours and then tested. The specimens were subjected to test the flexural and impact strengths.

Flexural strength test:

All samples were individually and horizontally mounted in a custom made loading fixture [three point bend test assembly; two parallel stainless steel rods with span length of 50 mm supporting the specimen, with the damage site centrally located on the tensile side] on a computer controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood,MA, USA) with a load-cell of 5 kN and data were recorded using computer software (Instron® Bluehill Lite Software). The load was applied perpendicular to the center of the repaired area until fracture at a crosshead speed of 5 mm/min (Fig. 2). The Stress-strain curves were recorded and the value of flexural strength (FS) of each specimen was calculated using the following formula:

FS (ό) =3F (L)/ 2wh²

Where,

F is the maximum load at the point of fracture.

L is span.

w is the width of the sample.

h is the height of the sample.

Impact strength test:

The impact strength of the specimens was measured by IZOD type of impact testing using Izod/Charpy Digital Impact tester (IZ-IM-266-01,
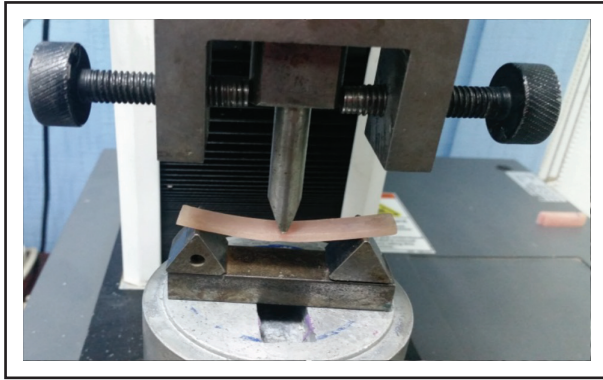
Fig. (2) Instron testing machine during Flexural strength test

Fig. (3) Izod/Charpy Digital Impact tester during impact strength test

International Equipments). The samples were clamped vertically in a metal fixture so that the middle of the sample at the notch coincided with the striking pendulum. The pendulum struck the specimen at the notched side until fracture was obtained. The test was performed with 0.5 J pendulum and a 150° lifting angle. The energy required to break the sample was measured in Joules (Fig. 3). Impact strength (IS) in KJ/m^2 was then calculated by the device's software using the following formula:

Impact strength (IS) = E / b x d

Where,

E is the absorbed energy.

b is the sample width.

d is the sample thickness.

Statistical analysis

The data were collected, tabulated, statistically analyzed and presented as descriptive statistics (means and standard deviations). Data were explored for normality using Kolmogorov-Smirnov test of normality. The results of Kolmogorov-Smirnov test indicated that most of data were normally distributed (parametric data). Statistical analysis was performed using **SPSS** (IBM Corp. IBM SPSS Statistics for Windows, Version 22.0 Armonk,

NY: IBM Corp). A probability level (P-value) ≤ 0.05 was considered statistically significant, less than 0.01 was considered highly significant. Paired t-test was used for testing the effect of addition of nanofillers in comparison to the control group.

RESULTS

Flexural strength

The mean and SD of flexural strength of the specimens are summarized in Table (2) and Fig.(4). The statistical analysis showed that the flexural strength increased significantly in the nano-ZrO$_2$ groups than the control group and also the flexural strength increased with the increasing of the concentrations of nano-ZrO$_2$ significantly (*P*< 0.01). The highest flexural strength was recorded for the 5% nanoZrO$_2$ fillers repair group (65.63±1.46 MPa), followed by the 2 % nano-ZrO$_2$ group (60.49±1.4 MPa) which also recorded higher significant mean value than the control group (52.88±1.35 MPa).

In both nano-Al$_2$O$_3$ groups, there was a highly significant reduction in the flexural strength where the repair group reinforced with 2% nano-Al$_2$O$_3$ recorded (46.41±1.55 MPa) and the repair group with 5% nano-Al$_2$O$_3$ showed the lowest flexural strength (34.57±1.48 MPa) compared to the control group.

Table (2) *Comparison between control group and the studied groups*

	Flexural strength (MPa)		P-value	Sig.
	Mean ± SD	Range		
CF	52.88 ± 1.35	50.78 – 55.02	–	–
2ZrF	60.49 ± 1.40	58.3 – 62.65	0.000	HS
5ZrF	65.63 ± 1.46	63.31 – 67.73	0.000	HS
2ALF	46.41 ± 1.55	44.03 – 48.76	0.000	HS
5ALF	34.57 ± 1.48	32.07 – 36.75	0.000	HS

Independent t-test

HS: Highly significant p < 0.01

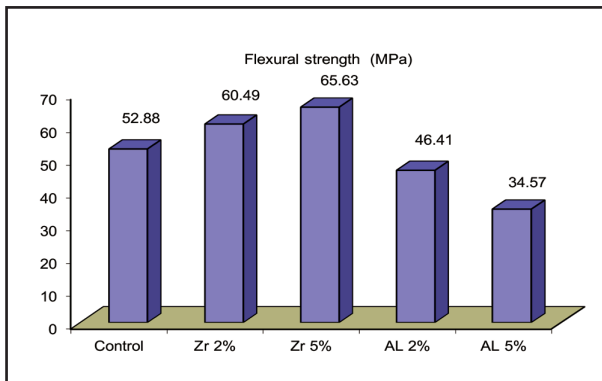*P-value in comparison with control group*

Fig. (4) Flexural strength results of study groups

Statistical analysis showed that there was a highly significant difference in the flexural strength mean values within the nano-ZrO_2 repair groups (2% and 5%) and also within the nano-Al_2O_3 (2% and 5%), as shown in (Table 3).

Table (3): *Comparison between Flexural strength of repair groups reinforced with 2% and 5% nano-ZrO_2 and nano-Al_2O_3*

Flexural strength (MPa)		2%	5%	P-value	Sig.
Nano-ZrO_2	Mean±SD	60.49±1.40	65.63±1.46	0.000	HS
	Range	58.3–62.65	63.31–67.73		
Nano-Al_2O_3	Mean±SD	46.41 ±1.55	34.57±1.48	0.000	HS
	Range	44.03–48.76	32.07–36.75		

Independent t-test   HS: Highly significant

Impact strength

Table (4) and Fig. (5) show the mean and SD of impact strength for the tested groups. The mean values of nano-ZrO_2 repaired groups were significantly higher than those of the control group ($P< 0.01$). The highest impact strength mean value was recorded for the 2% nanoZrO_2 fillers repair group (2.35 ± 0.04 KJ/m²) followed by the 5 % nano-ZrO_2 group (2.12 ± 0.11 KJ/m²) which also recorded higher significant mean values than the control group (1.96 ± 0.04 KJ/m²).

Regarding the 2% nano-Al_2O_3 repair group, there was a non-significant difference in the impact strength mean values (1.91 ± 0.10 KJ/ m²) than the control. While the repair group reinforced with 5% nano Al_2O_3 showed significant reduction in mean values (1.61 ± 0.06 KJ/m²) than the control group and it showed the lowest impact strength value.

Table (4) *Comparison between control group and the studied groups*

	Impact strength (KJ/m²)		P-value	Sig.
	Mean ± SD	Range		
CF	1.96 ± 0.04	1.89 – 2	–	–
2ZrI	2.35 ± 0.04	2.3 – 2.4	0.000	HS
5ZrI	2.12 ± 0.11	1.9 – 2.2	0.000	HS
2ALI	1.91 ± 0.10	1.7 – 1.98	0.138	NS
5ALI	1.61 ± 0.06	1.5 – 1.7	0.000	HS

Independent t-test;   NS: Non significant p> 0.05;

HS: Highly significant p < 0.01

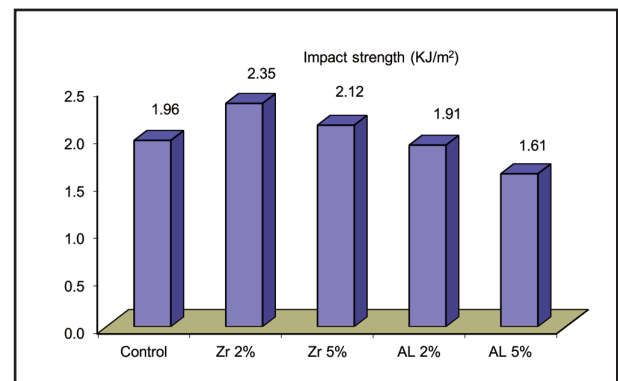*P-value in comparison with control group*

Fig. (5) Impact strength results of study groups

Statistical analysis showed that there was a highly significant difference in the impact strength mean values within the nano-ZrO_2 repair groups (2% and 5%) and also within the nano-Al_2O_3 (2% and 5%) groups, as shown in Table (5).

Table (5) *Comparison between impact strength of repair groups reinforced with 2% and 5% nano-ZrO_2 and nano-Al_2O_3*

Impact strength (KJ/m²)		2%	5%	P-value	Sig.
Nano-ZrO_2	Mean ± SD	2.35 ± 0.04	2.12 ± 0.11	0.000	HS
	Range	2.3 – 2.4	1.9 – 2.2		
Nano-Al_2O_3	Mean ± SD	1.91 ± 0.10	1.61 ± 0.06	0.000	HS
	Range	1.7 – 1.98	1.5 – 1.7		

Independent t-test   HS: Highly significant p < 0.01

DISCUSSION

Numerous techniques are utilized to restore the fractured resin dentures to their original strength. The preparation of the surfaces and sites to be joined is of paramount significance of ensuring prolonged service life of the prosthesis[42]. The method of repair has significant effect on strength of repaired denture [11]. The choice of repair material depends primarily on the strength of the repair material, the repair surface design, and the choice of repair material reinforcement [43]. The present study evaluated the effects of different concentrations of nano-fillers incorporated in repair resin on the flexural and impact strengths.

It was believed that noticeable improvement in the repair strength was found with the addition of nanoparticles, depending on the application and manipulation [41,43]. The incorporation of the nano-fillers to the polymer matrix was claimed to provide an opportunity for the enhancement of the mechanical properties of the resulted resin composite [44]. In addition to that, studies have shown that zirconia is biocompatible and had beneficial effects on mechanical properties [17,45].

The joint surface design has been proven to have a major impact on the strength of the repaired acrylic resin thus 45° beveling was used in this study as it was claimed that it increased the interface surface area and consequently provided a wide bond area. Mechanically, the 45° beveling might also shift the damaged area's tensile stress to the shear stress at the interface of the repaired specimens which consequently increase flexural strength [46,47].

It was stated that bonding between denture base and repair material can be enhanced by application of adequate chemicals to acrylic resin surfaces [30]. Thus, silanization was used in this study to improve the surface adhesion between the acrylic resin and the reinforced repair material [48]. It was stated that treating nano-fillers with silane coupling agent increased the chemical bond between the filler and acrylic resin [17] and increased the flexural properties of acrylic resin. In addition, silane-treated aluminum particles significantly increased the compressive, tensile, and flexural strength and the wear resistance of reinforced denture base resin [33,49,50].

For the evaluation of impact strength, there are two types of tests, CHARPY and IZOD [51]. These tests can result in different values, depending upon the loading configuration, specimen dimensions and presence of notches and their geometry [10]. Although there is a good correlation between the two tests, the absolute values differ from each other. The IZOD impact test was used in this study using notched samples were cantilevered, and a swinging pendulum was used to break the specimens. The reduction in the swing of the pendulum or the energy absorbed by the material was measured [52]. Regarding the impact strength testing specimens, the existence of a V-notch in its middle confirmed that the specimens were broken at the same point during testing [53].

Flexural strength

The addition of ZrO_2 nano-fillers increased flexural strength with both concentrations. This

result was in agreement with other studies [9,17] as it was proved that reinforcement of denture base resin with ZrO_2 nano-fillers powder results in an increase in its flexural strength [37,43].

In the present study, results were in agreement with the findings of a previous study that reported that the incorporation of ZrO_2 nano-fillers into acrylic resin enhanced the flexural strength of the repaired material [45]. This was complying with another study that found that the addition of 2.5% nano- ZrO_2 particles, 5% ZrO_2 nano-fillers, showed a statistically significant increase in flexural strength compared to the unreinforced autopolymerized resin. Authors attributed this increase in flexural strength to nano-ZrO_2 particle sizes, their distribution within the repair material, and the silanization process, along with the joint's surface design [41]. The flexural strength was improved by the addition of ZrO_2 nano-fillers. This was due to that these fillers were perfectly spread inside the polymer matrix and the subsequent interstitial filling of acrylic resin matrix with ZrO_2 which interrupted with the crack propogation [45,54]. However, other studies showed that increasing ZrO_2 nano-fillers up to 10% ZrO_2 filler particles, increased the transverse strength by 32%, whereas this increase was only 23% with the addition of 20% ZrO_2 nano-filler [17]. Another study revealed that with the addition of 7.5% nano-ZrO_2 particles, the maximum flexural strength value was recorded, but it had no statistical significance compared to the control group [41]. In addition, the transformation of ZrO_2 from the tetragonal to monoclinic phase resulted in absorbing the energy of crack propagation in a process called transformation toughening. In addition, during this process, the expansion of ZrO_2 crystals occurred and placed the crack under a state of compressive stress, which led to the arresting of crack propagation [55].

In this study, it was found that adding AL_2O_3 nano-fillers decreased the flexural strength of the repaired resin; this was in agreement with some studies. Several reasons could be behind the reduction of flexural strength, such as the stress concentration around the embedded metal and its poor adhesion to the polymer [56,57]. In addition to that, the reduction in the flexural strength may be due to; the concentration of too many stresses by high concentration of fillers which in turn changes the modulus of elasticity of the resin to be more stiff and void formation and air entrapment which would behave as weakening points for the continuity of the matrix resulting in facilitating the spread of the cracks inside the vicinity of the matrix with reduction in the total area of force distribution. Also, spaces creation in the polymer matrix with insufficient unity between the fillers and polymers might also play a role for such finding [38]. Another reason could be the harmful effect of the weak bond strength between the nano-fillers and the polymer matrix compared with the ZrO_2 [49].

Impact strength

In the present study, the incorporation of ZrO_2 nano-fillers improved the impact strength. The maximum improvement was noticed when the repair was done with the addition of 2% ZrO_2 nano-fillers. This might be explained by that the increase of impact strength was because of the spaces formed around the nano-fillers that lead to improvement in the impact strength by altering the pathway of growing cracks as a result of the perfect bond strength between the nano-fillers and polymer matrix. Also the growing cracks were arrested due to the nano-fillers being protected by formation of internal cross linking shear bonds between the fillers and the polymer matrix leading to increase the molecular bonding weight [37,58]. Values of 5% ZrO_2 nano-fillers were less than those of 2%. This was in agreement with another study [41] that found that increasing the ZrO_2 nano-fillers to 5% and more reduced the impact strength values. This reduction in impact strength might be due to the agglomeration of nano-ZrO_2 at 5 wt% which resulted in loosely bonded cluster formations. These larger agglomerations increased the stress concentration around the agglomerated nano particles and led to breaking

of the interactions at the interface and making the de-bonding between the auto polymerizing acrylic resin and nanoparticles powder which caused faster crack propagation [58].

In this study, the impact strength decreased with the addition of Al_2O_3 nano-fillers. 2% Al_2O_3 nano-fillers caused nonsignificant decrease of impact strength than the control group, while increasing the amount of Al_2O_3 nano-fillers to 5% caused highly significant impact strength decrease than control group. This reduction may be due to the fact of these particles brittleness and weakness in the ability of resistance to impact load comparing with acrylic resin matrix. Also might be because of aggregation of nanoparticles which had high surface energy [59].

CONCLUSION

Based on the results of the present study, reinforcement of repaired resin with nano-fillers has significant effect on strength of repaired denture base. The incorporation of nano-ZrO_2 into repair resins may improve the repair strength of the repaired denture base. This justifies the clinical importance of incorporation of nano-ZrO_2 into repair resins compared to unreinforced autopolymerized repair resins and Al_2O_3 nanofiller. Incorporation of Al_2O_3 decreased both flexural and impact strength, thus further investigations are recommended regarding other mechanical properties.

REFERENCES

1. Parvizi A, Lindquist T, Schneider R, Williamson D, Boyer D, Dawson DV. Comparison of the dimensional accuracy of injection-molded denture base materials to that of conventional pressure-pack acrylic resin. J Prosthodont 2004; 13: 83-89

2. John J, Gangadhar SA, Shah I. Flexural strength of heatpolymerized polymethyl methacrylate denture resin reinforced with glass, aramid, or nylon fibers. J Prosthet Dent 2001; 86: 424-427

3. Uzun G, Hersek N, Tinçer T. Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resin. J Prosthet Dent 1999; 81: 616-620

4. Jorge JH, Giampaolo ET, Machado AL, Vergani CE. Cytotoxicity of denture base acrylic resins: a literature review. J Prosthet Dent 2003; 90: 190-193.

5. Zhang X, Zhang X, Zhu B, Lin K, Chang J. Mechanical and thermal properties of denture PMMA reinforced with silanized aluminum borate whiskers. Dent Mater J 2012; 31: 903-908

6. Alhareb AO, Akil HM, Ahmad ZA. Impact strength, fracture toughness and hardness improvement of PMMA denture base through addition of nitrile rubber/ceramic fillers. Saudi J Dent Res 2017; 8: 26-43

7. Somkuwar S, Mishra SK, Agrawal B, Choure R. Comparison of the flexural strength of polymethyl methacrylate resin reinforced with multiwalled carbon nanotubes and processed by conventional water bath technique and microwave polymerization. J Indian Prosthodont Soc 2017; 17: 332-339

8. Vuorinen AM, Dyer SR, Lassila LVJ, Vallittu PK. Effect of rigid rod polymer filler on mechanical properties of poly-methyl methacrylate denture base material. Dent Mater 2008; 24: 708–713.

9. Yilmaz C, Korkmaz T. The reinforcement effect of nano and microfillers on fracture toughness of two provisional resin materials. Mater Des 2007; 28: 2063–2070

10. Zappini G, Kammann A, Wachter W. Comparison of fracture tests of denture base materials. J Prosthet Dent 2003; 90: 578-585

11. Mahajan H, Chandu GS, Mishra SK. An in vitro study of the effect of design of repair surface on the transverse strength of repaired acrylic resin using autopolymerizing resin. Niger J Clin Pract 2014; 17: 38-42.

12. AlHelal A, Goodacre BJ, Kattadiyil MT, Swamidass R. Errors associated with digital preview of computer-engineered complete dentures and guidelines for reducing them: A technique article. J Prosthet Dent 2018; 119: 17-25.

13. Beyli MS, von Fraunhofer JA. Repair of fractured acrylic resin. J Prosthet Dent. 1980; 44: 497-503

14. Polyzois GL, Andreopoulos AG, Lagouvardos PE. Acrylic resin denture repair with adhesive resin and metal wires: effects on strength parameters. J Prosthet Dent. 1996 ;75: 381-387

15. Stipho HD, Stipho AS. Effectiveness and durability of repaired acrylic resin joints. J Prosthet Dent 1987; 58: 249-253.

16. Heidari B, Firouz F, Izadi A, Ahmadvand S, Radan P. Flexural strength of cold and heat cure acrylic resins reinforced with different materials. J Dent (Tehran) 2015; 12: 316-323

17. 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. Saudi J Dent Res 2015; 6: 146–151

18. Shen C, Colaizzi FA, Birns B. Strength of denture repairs as influenced by surface treatment. J Prosthet Dent 1984; 52: 844-848

19. Polyzois GL, Handley RW, Stafford GD. Repair strength of denture base resins using various methods. Eur J Prosthodont Restor Dent 1995; 3: 183-186.

20. Thunyakitpisal N, Thunyakitpisal P, Wiwatwarapan C. The effect of chemical surface treatments on the flexural strength of repaired acrylic denture base resin. J Prosthodont. 2011; 20: 195-199

21. Pereira Rde P, Delfino CS, Butignon LE, Vaz MA, Arioli-Filho JN. Influence of surface treatments on the flexural strength of denture base repair. Gerodontology 2012; 29: e234-238.

22. Badr SE, Stone CR, Unger JW. A metal insert to replace a fractured segment of a mandibular complete denture. J Prosthet Dent 1989; 61: 250–251.

23. Vallittu PK. Dimensional accuracy and stability of polymethyl methacrylate reinforced with metal wire or with continuous glass fiber. J Prosthet Dent 1996; 75: 617–621.

24. Williamson DL, Boyer DB, Aquilino SA, Leary JM. Effect of polyethylene fiber reinforcement on the strength of denture base resins polymerized by microwave energy. J Prosthet Dent 1994; 72: 635–638.

25. Gad MM,1 Fouda SM, Al-Harbi FA, Näpänkangas R, Raustia A. PMMA denture base material enhancement: a review of fiber, filler, and nanofiller addition. Int J Nanomedicine. 2017; 12: 3801–3812.

26. Kostoulas I, Kavoura VT, Frangou MJ, Polyzois GL. Fracture force, deflection, and toughness of polymethyl methacrylate denture repairs involving glass fiber reinforcement. J Prosthodont 2008; 17: 257–261.

27. Tsue F, Takahashi Y, Shimizu H Reinforcing effect of glass-fiber-reinforced composite on flexural strength at the proportional limit of denture base resin. Acta Odontol Scand 2007; 65: 141–148.

28. Malquarti G, Berruet RG, Bois D. Prosthetic use of carbon fiber-reinforced epoxy resin for esthetic crowns and fixed partial dentures. J Prosthet Dent 1990; 63: 251–257.

29. Foo SH, Lindquist TJ, Aquilino SA, Schneider RL, Williamson DL, Boyer DB. Effect of polyaramid fiber reinforcement on the strength of 3 denturebase polymethyl methacrylate resins. J Prosthodont 2001; 10: 148–153.

30. Yadav NS, Khare S, Mishra SK, Vyas R, Mahajan H, Chitumalla R. In-vitro evaluation of transverse strength of repaired heat cured denture base resins without surface treatment and with chemical and mechanical surface treatment. J Int Oral Health. 2015; 7: 89-92.

31. Seó RS, Neppelenbroek KH, Filho JN. Factors affecting the strength of denture repairs. J Prosthodont 2007; 16: 302- 310.

32. Jordan J, Jacob KL, Tannenbaum R, Sharaf MA, Jasiuk I. Experimental trends in polymer. Nanocomposites – A review. Mater Sci Eng 2005; 393:1-11.

33. Asar NV, Albayrak H, Korkmaz T, Turkyilmaz I. Influence of various metal oxides on mechanical and physical properties of heat-cured polymethyl methacrylate denture base resins. J Adv Prosthodont. 2013; 5: 241–247.

34. Shuai C, Feng P, Yang B, Cao Y, Min A, Peng S. Effect of nano-zirconia on the mechanical and biological properties of calcium silicate scaffolds. Int J Appl Ceramic Technol 2015; 12: 1148–1156.

35. Mallineni SK, Nuvvula S, Matinlinna JP, Yiu CK, King NM. Biocompatibility of various dental materials in contemporary dentistry: a narrative insight. J Investig Clin Dent 2013; 4: 9–19.

36. Yu W, Wang X, Tang Q, Guo M, Zhao J. Reinforcement of denture base PMMA with ZrO_2 nanotubes. J Mech Behav Biomed Mater 2014; 32: 192–197.

37. Ahmed MA, Ebrahim MI. Effect of zirconium oxide nano-fillers addition on the flexural strength, fracture toughness, and hardness of heat-polymerized acrylic resin. WJNSE 2014; 4: 50–57.

38. Arora P, Singh SP, Arora V. Effect of alumina addition on properties of polymethylmethacrylate – A comprehensive review. IJMTT 2015; 9: 1–7.

39. Radzi Z, Abu Kasim NH, Yahya NA, Gan SN, Daud NM, Saffai L, Fadhel EA. Impact strength of an experimental polyurethane-based polymer. Annal Dent Univ Malaya. 2007; 14: 46–51.

40. Choksi RH, Mody PV. Flexural properties and impact strength of denture base resins reinforced with micronized glass flakes. J Indian Prosthodont Soc 2016; 16: 264–270

41. Gad MM, Rahoma A, Al-Thobity AM, ArRejaie AS. Influence of incorporation of ZrO_2 nanoparticles on the repair strength of polymethyl methacrylate denture bases. International Journal of Nanomedicine Int J Nanomedicine 2016; 11: 5633–5643

42. Memarian M, Shayestehmajd M. The effect chemical and mechanical treatment of the denture base resin surface on the shear bond strength of the denture repairs. Rev Clin Pesq Odontol Curitiba 2009; 5: 11-17

43. Gad M, ArRejaie AS, Abdel-Halim MS, Rahoma A. The reinforcement effect of nanozirconia on the transverse strength of repaired acrylic denture base. Int J Dentistry 2016: 1–6. Article ID 7094056

44. Al-Judy HJ, Ahmed AN, Abdul-Razak RW. Evaluation of Impact and Transverse Strength of Denture Bases Repaired with Nano Reinforced Resin. J Bagh Coll Dent 2016; 28: 9-15

45. Ayad NM, Badawi MF, Fatah AA. Effect of reinforcement of high-impact acrylic resin with zirconia on some physical and mechanical properties. Rev Clín Pesq Odontol Curitiba 2008; 4: 145-151.

46. Ward JE, Moon PC, Levine RA, Behrendt CL. Effect of repair surface design, repair material, and processing method on the transverse strength of repaired acrylic denture resin. J Prosthet Dent 1992; 67: 815–820.

47. Hanna EA, Shah FK, Gebreel AA. Effect of joint surface contours on the transverse and impact strength of denture base resin repaired by various methods: an in vitro study. J Am Sci 2010; 6: 115–125.

48. Ihab NS, Hassanen KA, Ali NA. Assessment of zirconium oxide nano-fillers incorporation and silanation on impact, tensile strength and color alteration of heat polymerized acrylic resin. J Bagh Coll Dent 2012; 24: 36–42.

49. Chaijareenont P, Takahashi H, Nishiyama N, Arksornnukit M. Effect of different amounts of 3-methacryloxypropyl-trimethoxy silane on the flexural properties and wear resistance of alumina reinforced PMMA. Dent Mater J. 2012; 31: 623–628

50. 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. J Prosthodont. 2012; 21: 546–551

51. Jagger DC, Jagger RG, Allen SM, Harrison A. An investigation into the transverse and impact strength of "high strength" denture base acrylic resins. J Oral Rehabil 2002; 29: 263-267.

52. Praveen B, Babaji HV, Prasanna BG, Rajalbandi SK, Shreeharsha TV, Prashant GM. Comparison of impact strength and fracture morphology of different heat cure denture acrylic resins: an In vitro study, J Int Oral Health 2014; 6: 12-16.

53. Shah SA, Khan S, Gulzar S, Khazir M. A research study to compare the flexural strength and impact strength of different heat cure and chemical cure acrylic resins under various conditions. Int J Health Sci Res 2015; 5: 325–329.

54. Jasim BS, Ismail IJ. The effect of silanized alumina Nano-filling addition on some physical and mechanical properties of heat cured polymethyl methaglate denture base material. J Bagh Coll Dent 2014; 26: 18-23.

55. Kenneth JA. Phillips' Science of Dental Materials. Philadelphia, PA: Saunders; 2003:703–704.

56. Abdulhamed AN, Mohammed AM. Evaluation of thermal conductivity of alumina reinforced heat cure acrylic resin and some other properties. J Bagh Coll Dent. 2010; 22: 1–7.

57. Vojdani M, Bagheri R, Khaledi AR. Effects of aluminum oxide addition on the flexural strength, surface hardness, and roughness of heat-polymerized acrylic resin. J Dent Sci. 2012; 7: 238–244.

58. Sun L, Gibson RF, Gordaninejad F, Suhr J. Energy absorption capability of nanocomposites: a review. Composites Sci Technol 2009; 69: 2392-2409.

59. Salih SI, Salih WB, Abdulghani SO. Preparation and Characterization the Flexural Properties and Impact Strength of PMMA Nano Composite Used For Denture Base. IJMETMR 2016; 3: 419-427.