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Evaluation Some of the Physical Properties of Poly Methyl Methacrylate-Zirconium Oxide Nanocomposite Denture Base Material

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Abstract

Aims: the current study aimed to add two concentrations of zirconium oxide nanoparticles (1.0 percent and 2.0 percent) to "heat-cured PMMA" in order to improve its characteristics such as transverse strength and impact strength. **Materials and Methods**: The particle size of Zirconium Oxide ZrO2 is 20nm. The ZrO2 nanoparticles were added to the "heat-cured PMMA" resin base at 1.0 percent and 2.0 percent by weight, respectively, to create a PMMA-ZrO2 nanocomposite of two various percentages to compare to PMMA without additives. For the transvers strength test and impact strength test, the traditional heat-curing technique was used with a water bath to polymerize the specimens. The data of the study were evaluated using a one-way ANOVA and a Duncan multiple range test with a significant P-value of (0.05). **Results**: An increase in transversal and impact strength for PMMA-ZrO2 nanocomposite of 1.0 and 2.0 percentages was noticed after comparison of the findings at (p0.05). **Conclusion**: By using Zirconium Oxide nanoparticles as dental filler at 1% and 2% by weight, the transverse strength and impact strength of PMMA denture base material were enhanced.

الخلاصة

الأهداف: تهدف الدراسة الى تقييم تأثير إضافة تركيزين(1.0٪ و 2.0٪) من جزيئات أكسيد الزركونيوم النانوية إلى البولي ميثيل ميثاكريليت المعالج بالحرارة لتحسين بعض الخصائص الفيزيائية مثل صلابة المسافة البادئة و خشونة السطح. **المواد وطرائق العمل:** بلغ العدد الإجمالي للعينات في هذه الدراسة 305 ، بينما كان عدد العينات في الدراسة التجريبية 80 عينة وعدد عينات الدراسة الرئيسية 225 عينة، تم فصلهم إلى ثلاث مجموعات بناءً على تركيز المادة المضافة من النانو أكسيد الزركونيوم. تم تصنيع العينات من البولي ميثيل ميثاكريليت المعالج بالحرارة مع جزيئات أكسيد الزركونيوم النانوية (1.0 و 2.0٪)، حيث كانت طريقة تحضير العينة المستخدمة في هذه الدراسة على النحو التالي: تم تحضير العينات أولاً بخلط كل تركيز بمفرده (بنسبة 1.0٪ و 2.0٪ مسحوق نانو أكسيد الزركونيوم) بالوزن مع مونومر سائل البولي ميثيل ميثاكريليت المعالج بالحرارة بعد ان تم طرح من وزن مسحوق البولي ميثيل ميثاكريلت بقدر ما تمت اضافته من مادة النانو أكسيد الزركونيوم ، ثم تم مزجها وتشتيتها في المونومر السائل بواسطة مسبار فوق صوتي بقوة 20 وات و 60 كيلو هرتز لمدة ثلاث دقائق ثم تمت إضافة مسحوق البوليمر ومزجها بنفس الطريقة لتجنب تكتل الجسيمات ، ثم تم اختبار العينات. **النتائج:** تم تحليل نتائج هذه الدراسة إحصائيا بواسطة (المعدل ± الانحراف المعياري ، الانوفا واختبارات المدى المتعددة لدانكن) و أظهرت هذه النتائج وجود فروق ذات دلالة إحصائية عند 0.05 في صلابة المسافة البادئة و خشونة السطح عند مقارنة المجموعات بإضافة أكسيد الزركونيوم بتركيز (1.0٪ و 2.0٪).
الاستنتاجات: استنتج من الدراسة، أن إضافة أكسيد الزركونيوم إلى البولي ميثيل ميثاكريليت المعالج بالحرارة ذو تأثير ايجابي على المركب النانوي المتولد من حيث صلابة المسافة البادئة و خشونة السطح ، علاوة على ذلك, لم يكن هناك فروق ذات دلالة إحصائية عند 0.05 بين 1.0٪ و 2.0٪ أكسيد الزركونيوم.

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INTRODUCTION

PMMA, or poly methyl methacrylate, is a biocompatible organic polymeric substance used to create denture bases [(1)]. It was first used in the manufacture of dentures in 1937. It is strong physical and mechanical properties have made it a suitable material since then [(2)]. Acrylic resins have been used and approved in all denture base materials, and it is estimated that (95%) of dental polymers are made up of "Poly methyl methacrylate" thermoplastic polymers [(3)].

PMMA, on the other hand, has poor mechanical properties and a low surface hardness when used alone. It was easily damaged by a strong impact or when a patient applied severe chewing pressures to the tooth's base [(4)].

Low mechanical properties against impact, bending, and fatigue, on the other hand, are major concerns that must be addressed in order to improve acrylic polymers for removable dental and acrylic appliances (5). The incorporation of inorganic nanoparticles into PMMA to improve their properties has recently received a lot of attention. Nanoparticle properties are determined by the type of nanoparticles used, their size and shape, concentration, and interaction with the polymer matrix [(6)].

Zirconium oxide is a metal oxide with numerous advantages, such as strong mechanical strength, toughness, rigidity, wear strength, chemical tolerance and good thermal stability, making it helpful to strengthen dental materials such as denture bases, also; zirconium oxide Nanoparticle has great strength, corrosion resistance, strong mechanical strength and abrasion resistance [(7)].

MATERIALS AND METHODS

It was decided to use a study sample of 60 specimens, which were split into two major groups. Impact and transverse mechanical tests were performed on the subdivided group of 30 specimens (n=30).

The proposed PMMA-ZrO_2 nanocomposite study was prepared according to the following measurements "the ZrO_2 of 1.0% wt. was added to the heat-cued PMMA resin base of 99% wt., ZrO_2 of 2.0% wt. was added to the heat-cued PMMA resin base of 98% wt, table (1). Using sensitive balance to achieve an even ZrO_2 distribution within the PMMA matrix", then; the sample preparation was done by mixing 1.0% and 2.0% by weight ZrO_2 nano powder with "heat-cured PMMA" fluid monomer, then; sonicated and dispersed in the liquid monomer by an ultrasonic probe of 20W and 60 kHz for three minutes, after that; the "heat-cured PMMA" polymer powder was added and sonicated in the same way to avoid particles agglomeration [(8)].

Table (1): Amounts of added percentages of ZrO_2 with PMMA by weight

Zirconium oxide	Heat-cured PMMA powder
1.0%	99.0%
2.0%	98.0%

For full dentures, a traditional flaking process was used during mold preparation. Separating media (cold mold stitch) were used and allowed to dry before placing the lower part of metal bottles filled with dental stone and combining in vibration according to the manufacturer's directions to remove trapped air, then leaving to set. The plastic model was made out of acrylic sheets that were designed using computer software (AutoCAD) and then engraved using a computer-controlled laser cutting machine. The length, width, and thickness of the plastic models used in the mold fabrication were precisely measured to meet the requirements for each test. The specimens were washed and stored in distilled water at 37°C for two days before being analyzed in both groups [4].

Testing Procedures

Indentation hardness test:

The test was performed using an indenter in the shape of a 1.25 mm round steel ball. Shore D hardness testers from China (SHAW) were utilized.

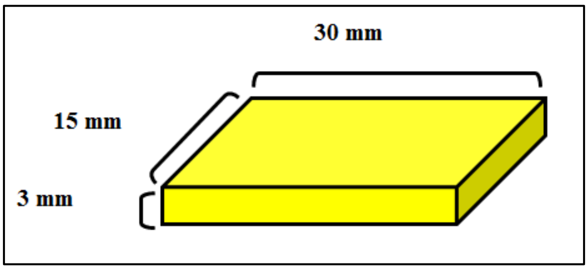

Figure (1): Hardness testing specimen dimensions.

The specimens were prepared according to ADA specification with dimensions of "30mm length × 15mm width × 3mm thickness ± 0.03 mm" [9], Figure (1).

The SHAW hardness tester has been reset before being used at each time for tests, and it was finished by confirming that the zero reading implies that the indenter does not have an external force; the reading should not be greater than one or under zero. However, the SHAW hardness tester should not be higher than 100 or less than 99 when it has been pulled off fully when the indenter is pushed against the flat glass plane.

The surfaces of the specimen have been examined at three separate locations for hardness and the mean for each specimen has been determined. The sample had a set load of 44.5 N, after applying this load the hardness number had been recorded following the instructions of the machine.

Surface roughness test:

The samples have been made with ISO measurements "10mm length ×10mm width ×2mm thickness" in accordance with Nevzatoġlu et al [10], as indicated in the Figure (2).

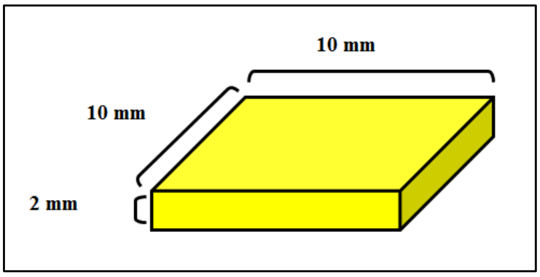

Figure (2): Surface roughness testing specimen dimensions.

Surface roughness (Ra) values are calculated using a profilometer, which can detect minute changes on the surface by moving a diamond style in contact with the specimens while moving laterally across them. The surface variations are caused by the vertical movement of the stylus. The stylus tip range of the machine was 2.5m, with a scan length of 0.8mm [11]. The specimen surface roughness was assessed directly, 10 specimens from each group were measured. Five measurements were carried out and a mean value was measured for each sample and utilized for statistical analysis; then, the specimens of surface roughness were compared to the control group for each group.

RESULTS

Indentation hardness test:

Table (2) was shown the results of a statistical analysis of hardness test for all groups that were tested.

Table (2): Descriptive statistical analysis of hardness test

Groups	Descriptive Statistics				
	N	Minimum	Maximum	Mean	Std. Deviation
Control	30	91	99	95.53	2.623
ZrO_2 1.0%	30	1	3	2.00	0.830
ZrO_2 2.0%	0				

Significant differences were found in the one way analysis of variance (ANOVA) of the (1.0% ZrO_2 and 2.0% ZrO_2) groups and control group were shown in table (3).

Table (3) ANOVA was used to compare the indentation hardness of different ZrO_2 groups

SOV	SS	df	MS	F	Sig.
Between Groups	134.067	2	67.033	27.674	.000
Within Groups	65.400	27	2.422		
Total	199.467	29			

SOV: Source of variance; SS: Sum of squares; df: degree of freedom; MS: Mean square

Duncan's multiple range test Figure (3) revealed a significant difference between the (1.0% and 2.0%) ZrO_2 & the control groups. There was no significant difference between the (1.0% and 2.0%) ZrO_2 groups, with the (2.0%) ZrO_2 group was slightly higher than the control groups and (1.0%) ZrO_2.

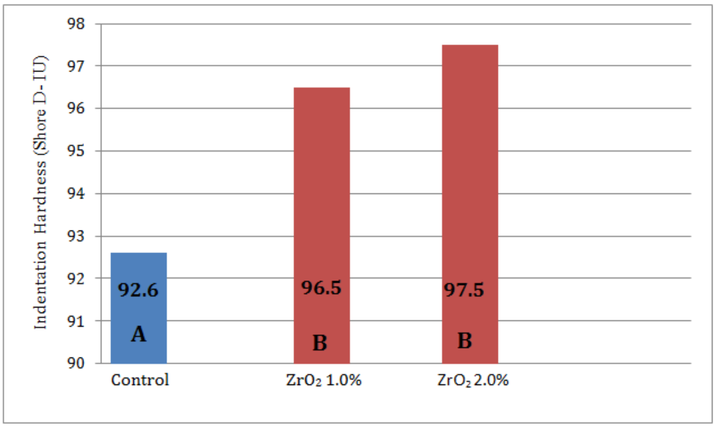

Figure (3) ZrO_2 groups were compared using mean, standard deviation, and Duncan's multiple range test of indentation hardness.

Surface roughness test:

Table (4) was shown the results of a descriptive statistical analysis of surface roughness for all of the groups that were tested.

Table (4) Descriptive statistical analysis of roughness test

Groups	Descriptive Statistics				
	N	Minimum	Maximum	Mean	Std. Deviation
Control	30	0.1	0.44	0.2136	0.0982
ZrO_2 1.0%	30	1	3	2.00	0.830
ZrO_2 2.0%	0				

Significant differences were found in the one way analysis of variance (ANOVA) of the (1.0% ZrO_2 and 2.0% ZrO_2) groups and control group table (5).

Table (5) ANOVA was used to compare the surface roughness of different ZrO_2 groups

SOV	SS	df	MS	F	Sig.
Between Groups	0.187	2	0.094	27.207	.000
Within Groups	0.093	27	0.003		
Total	0.280	29			

SOV: Source of variance; SS: Sum of squares; df: degree of freedom; MS: Mean square

Duncan's multiple range test Figure (4) revealed a significant difference between the (1.0% and 2.0%) ZrO_2 & the control groups. There was no significant difference between the (1.0% and 2.0%) ZrO_2 groups, with the (2.0%) ZrO_2 group was substantially higher than the control groups and (1.0%) ZrO_2.

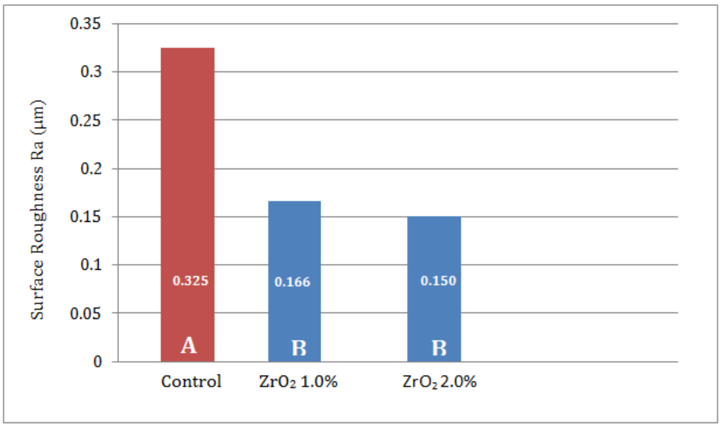

Figure (4) ZrO_2 groups were compared using mean, standard deviation, and Duncan's multiple range test of surface roughness.

DISCUSSION

Indentation hardness test:

After addition of Zirconium oxide nanoparticle at 1.0 percent (96.5 IU) and 2.0 percent (97.5 IU), the mean values of shore D hardness were significantly higher as compared to the control group (92.6 IU). The statistical findings were shown significant higher mean values of 1.0% ZrO_2 of (96.5 IU) and 2.0% ZrO_2 of (97.5 IU) when compared to the control group which was (92.6 IU).

There is also the possibility that the nanoparticles affect the elastic modulus of the PMMA, which increases the hardness of the produced nanocomposite [12, 13], since the modulus of elasticity of PMMA is proportional to the hardness property [14]. Adding nanoparticles to PMMA may enhance its stiffness and hardness, as the nanoparticles prevent chain motion by increasing the crosslink density [15]. There is a correlation between filler loading and hardness of reinforced PMMA, according to this study. The nano zirconia dispersion uniformity inside the material was also shown to be a significant factor. In addition, the increased cross-linking density of the nanocomposite made it more stiff and resistant to penetration.

This substantial improvement in hardness may agree with the results of another study by Fatalla *et al*., (2020) in which ZrO_2 nanoparticles were added to "heat-cured PMMA" (4).

Surface roughness test:

The contact stylus tracing method was used in this study because it was simple, fast, and reliable for determining surface roughness. Surface roughness mean values decrease considerably after the addition of Zirconium oxide nanoparticles in the 1.0 % (0.166 m) and 2.0 % (0.150 m) groups, respectively, when compared with the control group (0.325 m) and that means the addition of zirconium nanoparticles will decrease the surface roughness the cause that make it advantageous material to be used in many situations worldwide.

The current study's findings were similar with Akash and Guttal's (2015) research, which demonstrated that increasing the concentration of nanoparticles would cause a reduction in dispersion inside the polymer matrix, a conclusion was corroborated by the SEM imaging result.

CONCLUSION

The Addition of Zirconium Oxide nanoparticles as a dental filler (1.0% and 2.0% by wt.) to PMMA denture base material enhanced the material's indentation hardness and decreased its surface roughness.

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