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The Effect Of CAD/CAM Waste on Mechanical Properties of Heat Cure Acrylic Resin

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Abstract

Background: Being healthcare professionals, technicians must be aware of the safe disposal of biomedical waste and the recycling of dental materials to reduce biological risks to the environment. Objectives: Aim of the current study to evaluation the PMMA surface roughness and hardness after recycling and reuse of waste zirconia material from the CAD/CAM production method as effective filler. Materials and Methods: The Zirconia fiber was collected from the CAM machine after the milling procedure. Then, standard sieves for ISO standardization no. 40, 60 and 100 were used respectively to reach a fine grain size of 150µm. Zirconia of 1% wt. it was added to the PMMA resin base of 99% wt., Zirconia of 3% wt. it was added to the PMMA resin base of 97% wt and Zirconia at 5% wt. it has been added to PMMA resin base of 95% wt. to reach a PMMA/Zirconia composite of three different filler ratios then compared with Polymethyl methacrylate without additives. The conventional heat-curing method using a water bath was applied to polymerize the disc samples for both surface roughness and hardness tests. The data of this study are analyzed by One-way ANOVA (post-hoc/Tukey test) performed at a significant P-value of ($p \leq 0.05$) and a 95%confidence level. Results: After comparing the results, a significant difference was observed in the surface roughness and hardness of PMMA/5% Zirconia composites compared to other tested groups ($p \leq 0.05$). Conclusion: The 1%, 3% and 5% wt. of Zirconia -fibers as a filler would be an effective percentage to decrease the surface roughness of the PMMA 5% wt. of Zirconia -fibers as a filler would be an effective percentage to increase the surface hardness of the PMMA.

Introduction

Biomedical waste management has become a concern in the dental world as different materials start to increase in use.

In dentistry, few studies have suggested to recycle and reuse some of the dental materials (1, 2). The majority of such study population was completely clueless regarding knowledge pertaining to the recycling process. They were unaware of the proper disposal of some non-degradable dental materials (3, 4, 5, 6). Acrylic resin polymethyl methacrylate (PMMA) has been the most popular material for the construction of dentures for many decades as it has many advantages such as stability, good aesthetics, accurate fit, in the oral environment, inexpensive equipment's, easy clinical and laboratory manipulation (7, 8, 9). Although it is the most commonly used in dentistry for the manufacture of the denture bases, this material is still insufficient to meet the ideal mechanical requirements for dental applications. This problem is mainly due to low plaque accumulation and fracture resistance (10, 11).

The zirconium oxide Nano-particles powder was determinant to improve the properties of polymethyl methacrylate, as a bio-compatible material possessing high fracture resistance, and to improve fracture toughness of ceramics by developing a new generation of ceramic-matrix composites (12, 13, 14).

Zirconium oxide ($ZrO2$) is a metal oxide that possesses several advantages such as good mechanical strength, fracture toughness, hardness, wear and chemical resistance, and good thermal stability, thus making it beneficial for use in dental materials such as denture base reinforcement (15, 16). $ZrO2$ is a polymorphic material, is available in three stable phases: monoclinic, tetragonal, and cubic. The properties of $ZrO2$ differ according to the phase types. The tetragonal phase is a catalytic phase, and it is a mechanically interesting phase compared with the other phases. Tetragonal phase $ZrO2$ can be stabilized at room temperature with divalent and trivalent cationic species such as magnesium, calcium, and yttrium (17, 18).

Materials and Methods

1. Zirconia-Waste Fiber Collection

In the current study, a decomposed Zirconia blank was used. The Zirconia fiber was collected after using the CAD-CAM production method (Vita/zahnfabrik, Germany). The result fiber was brushed-off from the CAM machine after dry milling procedure (Roland- DWX-50, USA). Then a magnet is used during vibrating sieving procedure to remove any trace of metal particles may incorporated from the cutting bur. The standard stainless steel sieves of ISO standardization (Italy) no. 40 (420μm), 60 (250μm), and 100 (150μm) respectively was used to achieve fine particle grit sizes (19, 20).

2. Preparing the PMMA/Zirconia Composite

The composite materials for the proposed PMMA/Zirconia study were prepared according to them by following the measurements using the sensitive balance as shown in Table (1). To reach an even Zirconia distribution of the fibers inside PMMA powder, each prepared amount was distribute using a dispensing unit at 40 rpm/min for 5 h (12,000 rpm).

3. Study Sample Grouping

A specimens of 40 disc samples was prepared for this study, and it was divided into four major groups. The subgroup was tested for surface roughness and mechanical hardness tests, (n = 10).

Group I: 10 specimens control group without aiding Zirconia.

Group II: 10 specimens with 1% wt Zirconia.

Group III: 10 specimens with 3% wt Zirconia.

Group IV: 10 specimens with 5% wt Zirconia.

The X-ray diffraction (XRD) was used to analyses the effect of the Zirconia filler on the PMMA crystallinity behavior. The XRD technique indicates the normal order of crystalline structure in the polymeric chains. XRD pattern was obtained in the 2θ range between 0 and 90 degree (LabX6000-Shimadzu, Japan).

4. Sample Preparation

The silicone mold for wax disc samples was prepared for surface roughness and hardness tests. The dimensions were 12 (± 0.1) mm in diameter and 2 (± 0.1) mm thickness as shown in Figure (1). The treated PMMA and PMMA/Zirconia compounds followed the traditional formulation method using a water bath curing system. The mixing ratio of PMMA powder/liquid is according to the manufacturer's instructions by volume (1/3) (Veracril, Spain). The short-cycle thermoplastic polymerization method was timed for 3house. After curing, the flasks were kept on abench to cool overnight, deflasked, sample flashes removed, and cleaned of the gypsum product using an ultrasonic unit for 15 min.

5. Testing Procedure

Figure (2) shows the surface hardness that measured using Shore D durometer hardness tester unit (China) and the surface roughness which measured using the profilometer surface roughness tester device (China), the contact pin was using during tracing. The analyzing tip of the durometer traveled 5 mm at the surface center for each specimen.

Statistical Methods

Study data were analyzed by one-way ANOVA (Post-hoc test, Tukey) with a confidence level of 95% and a significant P-value of ($p \leq .05$).

Result

The descriptive statistics of the values including the means and standard deviation (SD) values for each subgroup of surface roughness showed that control group had the higher mean value in surface roughness (1.4620) and the lowest mean value was found in group containing 3%ZrO_2 (0.0466) as shown in Tables (2) and Figure (3). The result of surface hardness it was found that the PMMA+5%ZrO_2 yielded the highest average mean values (74.5000±0.94281), followed by the PMMA control group (74.3500±2.72896), and PMMA+1%ZrO_2 (58.5000±3.38296) while the lowest average mean values were obtained for PMMA+3%ZrO_2 (58.0000±2.34521) as show in Table (3) and Figure (4).

Discussion

The initial mechanical properties of any dental material may predict the primary mode of clinical failure and provide a determination for a specific application. Recently, the development of new materials for the load-bearing areas were suggested to improve the mechanical properties. PMMA was one of the most commonly used denture bases with inferior mechanical properties. In the present study, the surface hardness and roughness of PMMA base resin are evaluated after the addition of 1%, 3% and 5% of Zirconia fiber.

The effect of Zirconia waste fiber on surface roughness

Surface irregularities on denture base materials may act as a reservoir of infection and increase the potential for hosting microorganisms even after dentures have been cleaned, and rough surfaces facilitate penetration of fungal and bacterial cells onto denture base resins (10). It is important to determine the materials surface roughness used in dental prostheses before they are used in the mouth. Rough surfaces can cause discoloration of the prosthesis, be a nuisance to patients and may also contribute to biofilm formation and microbial colonization. Fungal and bacterial species tend to adhere to the rougher denture base materials. Previous studies indicate a surface roughness threshold level for dental materials used in the oral cavity of Ra = 0.2 µm where no further decrease in plaque accumulation would be expected below this level (12).

In the present study, result showed that control group with non -additive had the higher mean value in surface roughness (1.4620) and the lowest mean value was found in group containing 3%ZrO_2 (0.0466). This may be attributed to, that the Zirconia possesses many advantages like good mechanical strength, hardness toughness, chemical and wear resistance, and good thermal stability, which makes it

useful to use in dental material like strengthening of denture base (13,15).
Another reason to reduce the surface roughness when a cutting tool is used to cut a workpiece, there will be a residual cutting face on the surface, feed rate, main/auxiliary deflection angle and the radius of the tooltip arc, which will affect the size of the residual face. Adjust the feed rate and angle in the machining process can reduce the surface roughness and cutting area of the part. In addition, the lubricant and cutters selected should conform to the characteristics of the material, to reduce roughness and inhibit the formation of tool burr and scale (10).

This coincide with (Kareem and Moudhaffer, 2015; Michael et al., 2019) they found that the addition of Zirconia fiber causes decreased surface roughness (14, 16).

The effect of zirconia waste fiber on surface hardness

Hardness is an important property that acrylic materials to be used as base resins for dentures because of their resistance to occlusal forces. This property also provides resistance to abrasion and scratching, and is directly related to the arrangement of materials, chemistry, and mode of polymerization. Hardness is defined as the resistance of an indentation and is determined by measuring the permanent depth of the indentation using various test methods. Commonly used hardness test methods are Vickers, Brinell, Shore, Knoop, and Rockwell (7).

In the current study it was found that the PMMA+5%ZrO2 yielded the highest average mean values in surface hardness in all the tested group, this the increase in surface hardness of 5%ZrO2 could be related to the particle sizes, their distribution of the Zirconia fillers and the good mechanical properties of Zirconia within the matrix resin denture material (20), followed by the PMMA control group and PMMA+1%ZrO2 while the lowest average mean values were obtained for PMMA +3%ZrO2. The result in this study revealed that the additions of Zirconia waste fiber to the PMMA base resin increased the surface hardness of PMMA than that of non-additives. The annealing process for the material provided a high crystallinity behavior for CAM purposes, the increase in the Zirconia fibers filler percentages could affect positively the surface hardness (5).
This result came in agreement with (Zidan, 2020; Chathuranga et al., 2021) they state that the material hardness may increase by the presence of polymer of high crystallinity polymer and the addition of Zirconia fiber to heat cure acrylic effects the surface hardness of the material (9, 17).

Conclusion

The 1%, 3% and 5% wt. of Zirconia -fibers as a filler would be an effective percentage to decrease the surface roughness of the PMMA. 5% wt. of Zirconia -fibers as a filler would be an effective percentage to increase the surface hardness of the PMMA.

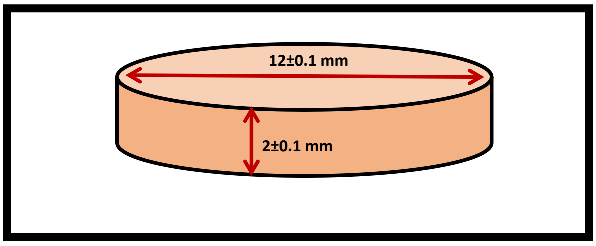

Fig. (1): Surface hardness and roughness specimen dimensions

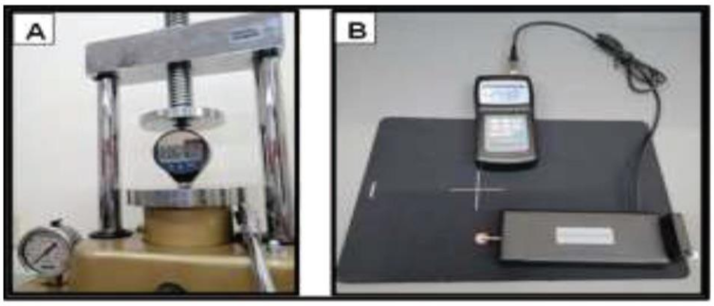

Fig. (2): A, Shore D durometer surface hardness unit; and B, Surface roughness profilometer tester device.

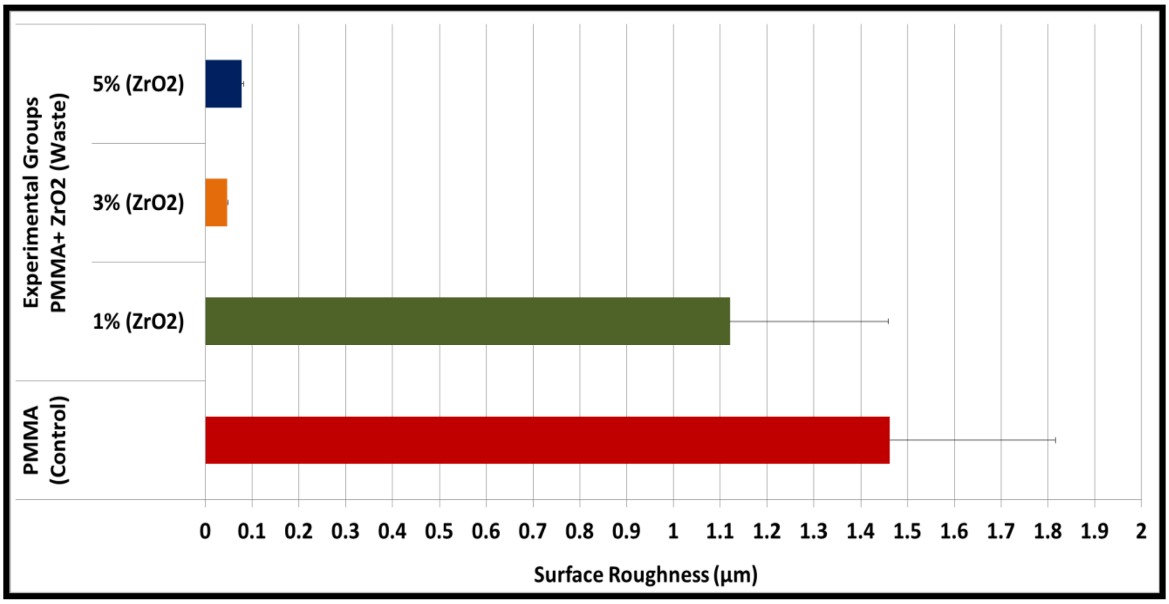

Fig. (3): Bar chart graph showing the mean distribution of the surface roughness of all groups

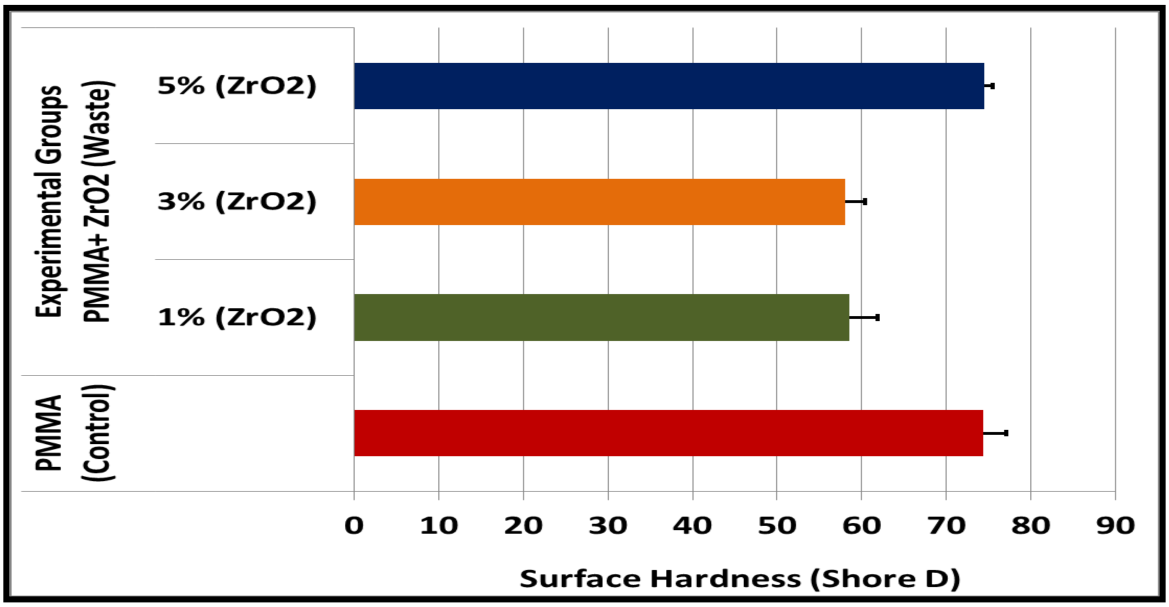

Fig. (4): Bar chart showing the mean distribution and standard deviations of Vickers hardness number (VHN) of the studied groups.

Table (1): The composition of PMMA-Zirconia composite for the experimental groups

Groups	**PMMA Composite Resin**	
	Resin-Base (95-100 wt. %)	**Zirconia-Fibers (0-5 wt. %)**
	PMMA (g)	**Zirconia (g)**
Control (I)	100%	0%
Group (II)	99%	1%
Group (III)	97%	3%
Croup (IV)	95%	5%

Table (2): Descriptive statistic of the surface roughness of the different groups measured (in μm)

Groups	Mean	Std. Deviation	N
PMMA	1.4620	0.35398	10
PMMA+1%ZrO2	1.1205	0.33846	10
PMMA+3%ZrO2	0.0466	0.00178	10
PMMA+5%ZrO2	0.0773	0.00460	10
Total	0.6766	0.67669	40

Table (3): One-way (ANOVA) test showing the surface roughness of the tested group specimens.

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
PMMA	PMMA+1%ZrO2	.3415	.15487	.160	-.0963	.7793
	PMMA+3%ZrO2	1.4154*	.11194	.000	1.0660	1.7648
	PMMA+5%ZrO2	1.3847*	.11195	.000	1.0352	1.7342
PMMA+1% ZrO2	PMMA+3%ZrO2	1.0739*	.10703	.000	.7398	1.4080
	PMMA+5%ZrO2	1.0432*	.10704	.000	.7091	1.3773
PMMA+3% ZrO2	PMMA+5%ZrO2	-.0307*	.00156	.000	-.0353	-.0261

Table (4): Descriptive statistic of the surface hardness of the different tested groups.

Groups	Mean	Std. Deviation	N
PMMA	74.3500	2.72896	10
PMMA+1%ZrO2	58.5000	3.38296	10
PMMA+3%ZrO2	58.0000	2.34521	10
PMMA+5%ZrO2	74.5000	.94281	10
Total	66.3375	8.54129	40

Table (5): One-way (ANOVA) distributions of micro-hardness of the tested groups.

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
PMMA	PMMA+1%ZrO2	15.8500*	1.37447	.000	11.9483	19.7517
	PMMA+3%ZrO2	16.3500*	1.13786	.000	13.1270	19.5730
	PMMA+5%ZrO2	-.1500	.91302	.998	-2.8930	2.5930
PMMA+1 %ZrO2	PMMA+3%ZrO2	.5000	1.30171	.980	-3.2235	4.2235
	PMMA+5%ZrO2	-16.0000*	1.11056	.000	-19.3746	-12.6254

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