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Assessment of the Compressive Strength and Surface Roughness of Acrylic Denture Bases Reinforced with Ostrich Eggshell Powder

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Abstract

Aim of the study: The material most frequently employed in the dental industry is polymethyl methacrylate (PMMA). Temporary dental restorations, including those for complex indications such as implants or large-span bridges, are manufactured using this material. However, its numerous limitations render it unsuitable for application in all situations. Consequently, individuals utilizing removable prostheses must be concerned regarding the potential for fracture. Examined the effects of various particle sizes of 5% hydroxyapatite (which was prepared from ostrich eggshell powder**)** on the roughness and compressive strength of heat-cured acrylic resin

Material and method: A total of 28 cylindrical samples composed of pink heat-treated acrylic resin were fabricated and subsequently categorized into four experimental groups; Group A (Control without any additive), Group B (Particle size 80µm), Group C (Particle size 70 µm), and Group D (Particles Size 50 µm). Each group consisted of seven samples categorized according to the varying sizes of hydroxyapatite particles. The test groups homogenously blended at a weight percentage of 5% of ostrich eggshell powder. Subsequently, an assessment was conducted to determine the collective compressive strength and surface roughness of this groups.

Results: The results of the investigation showed significant variations in compressive strength for group B (107±3.742 MPA), group C (103.43±5.192 MPA), and group D (98.43±7.323 MPA) concerning the different sizes of hydroxyapatite particles compared to group A (74±4.163 MPA). While there was a significant increase in surface roughness for groups B (3.22±0.014), C (2.41±0.018), and D (2.36±0.077) compared to group A (1.451±0.073).

Conclusion: Varying the particle size of hydroxyapatite added to the thermosetting acrylic resin (80µm, 70µm, and 50µm) increases both the material's compressive strength and surface roughness.

Keywords: heat-cured acrylic, dried ostrich eggshell powder, compressive strength, roughness.

Introduction

For a long time, polymethyl methacrylate (PMMA) was the most often utilized acrylic resin in the creation of denture bases. Acceptable mechanical, physical, and aesthetic qualities are present in this resin (Alqutaibi et al., 2023). Additionally, it has several benefits low cost, straightforward manufacture, acceptable aesthetics, lightweight, good optical qualities, the ability to match colors, biocompatibility, and simplicity in finishing and polishing (Rakhshan, 2015). Denture-based materials that are effective for edentulous patients must, among other things, possess exceptional mechanical properties. PMMA is considered the optimal material for denture bases due to its favorable compliance with a multitude of criteria, including sufficient strength, acceptable aesthetics, manageability, thermal stability, dimensional stability, and insolubility in oral fluids

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(Alqutaibi et al., 2023). Nevertheless, PMMA tends to fracture after long clinical use (Ghasemi et al., 2023). Other substances, such as metals, carbon, and glass fibers, have also been tested but were found unsuitable as reinforcement elements for acrylic resins. Metals were viewed as being too challenging to manipulate (Yu et al., 2012). Modifying acrylic resins has garnered more interest and attention because of some of their disadvantages, including inferior mechanical qualities, water absorption, accuracy of fit, and polymerization shrinkage (Abdullah, 2023). To create microcrystalline HA, several researchers have used a variety of biogenic materials, including corals, eggshells, fish scales, seashells, animal bones, etc., as a calcium supply (Muthu et al., 2022). Various biomedical fields, including dentistry, bone substitutes, and hard tissue paste utilize hydroxyapatite (HA) [Ca10 (PO4)6(OH) 2]. Numerous clinical uses for hydroxyapatite (HA) reinforced polymers exist, including the covering of joint replacement prostheses, dental implants, and bone cement (Habibah et al., 2018). Hydroxyapatite is a mineral compound composed of calcium, phosphorus, oxygen, and hydrogen. It is a type of apatite and is the main component of ivory and bones in the human body. Hydroxyapatite is known for its excellent properties, such as hardness, resistance to corrosion, and interaction with living tissues. As a result, it is used in various important medical and scientific applications (Nayak, 2010). Researchers are interested in the physicochemical properties of eggshells to obtain natural calcium sources for the manufacturing of biodiesel. The eggshells of several bird species have a significant amount of calcium carbonate (CaCO3) and similar chemical properties (Caliman et al., 2017).

This in vitro investigation aimed to identify the impact of 5% concentrations of ostrich eggshell hydroxide with varying particle sizes on the denture base polymer's compressive strength and surface roughness. In contrast to the control group (without hydroxide addition), the null hypothesis was that the hydroxide of ostrich eggshell with different particle sizes at the same concentration and molding processing method would result in variations in the mechanical properties tested (compressive strength and surface roughness).

2. Materials and Methods

2.1. Preparation of silicon mold and sample

Following ADA standard NO.12 (AL-Ghabban et al., 2009)**.** A silicone mold in the shape of a disc that is 6 mm across and 12 mm thick is used in Figure 1. The drop-by-drop method of the Lacron cutting tool used to make the study sample was used to melt the base plating wax and then pour it into the silicon mold in small amounts.

Following the collection of twenty-eight wax samples, the flasking procedure was implemented. The dental stone was mixed with water in a rubber container following the manufacturer's guidelines. To remove air pockets, the stone is subjected to a vibrating motion. Following this, a wax disc was inserted into the center of the dental stone surface as the mixture was poured into the lower section of the flask. A separator medium is subsequently applied to the stone's surface after it has hardened for one hour. Grams per 25 milliliters is the standard powder-to-water ratio of stone. Through the

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aperture in the upper section, dental stones are introduced into the receptacle, which is situated above the lower section. Following the addition of one hour for complete solidification, the vial was sealed with a cover. Upon opening the flask, the patterns were removed with care to avoid any potential distortion. After that, a separating medium was applied to both flask sides to prepare them for filling with acrylic dough.

Figure 1: The silicon mold

2.2. Preparation of hydroxyapatite

The process of producing hydroxyapatite from ostrich eggshells comprised the subsequent procedures: Eggs from ostriches acquired from regional markets. With great care, the eggshells were extracted, and the inner membrane was stripped away. A comprehensive cleansing process utilizing distilled water is employed to eliminate any residual inner membrane. The eggshells are then ground using a grinding device to obtain small particles. After subjecting these particulates to an oven preheated to 900 °C for one hour, the substance underwent a complete transformation, becoming a powdery white color. This is because calcium carbonate, the main component of eggshells, breaks down into carbon dioxide and calcium oxide when heated. Following this, phosphoric acid was added to the aqueous suspension of calcium oxide at a concentration of 0.6M while the mixture was continuously stirred. This resulted in hydroxyapatite formation. Following cooling to room temperature (22±3 °C), the mixture underwent filtration through a Buchner funnel and underwent multiple washes with distilled water. Following this, the product was desiccated and sterilized at 110°C in an oven (AL-Bahar, 2014). Following this, hydroxyapatite was subjected to sieving using different mesh sizes in order to achieve particle sizes of 50µm, 70µm, and 80µm.

2.3. Preparation of PMMA/HA

PMMA and 5% HA combined to produce the powder component, which had particle diameters of 50µm, 70µm, and 80µm for each group. As data in Table 1. a mixture was formed between the particulate and liquid components. Once the dough formed, the mixture was compressed into a flask at ambient temperature for 25 minutes at a pressure of 14 MPa using a compressor. The polymerization process was conducted in a water immersion for 90 minutes at 78°C.

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Table 1: Proportion of PMMA/HA used in the study.

Groups	Hydroxyapatite 5%	Amount of acrylic powder (g)	Amount of monomer (ml)
Group (A)	0	30	18
Group (B) Hydroxyapatite (80µm particle size	1.5	28.5	18
Group (C) hydroxyapatite (70µm particle size)	1.5	28.5	18
Group (D) hydroxyapatite (50µm particle size)	1.5	28.5	18

2.4 Mechanical and physical tests

Compressive strength

The compressive strengths of the samples were assessed utilizing "universal testing equipment" that was controlled by a computer at a crosshead velocity of 1 mm/minute and a loading rate of 5 KN/min. Figure 2 illustrates the sample in the intermediate position between the Instron universal testing apparatus and the metallic testing table. The specimens fragmented as a result of the compressive force that increased continuously; digitalized values in Newton/mm2 (MPa) were recorded at each point. The values of compressive strength for each sample were computed.

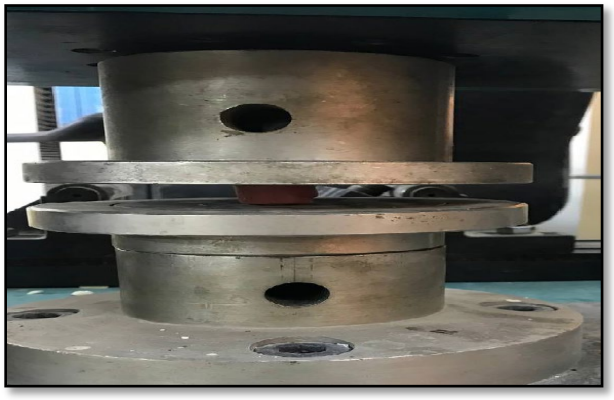

Figure 2: Sample under compressive strength device

Surface roughness

The test was conducted using a profilometer device (surface roughness tester srt-6200s BESTONE Group Inc, China). When the specimen is positioned horizontally firm on a smooth table in compliance with the device's directions, the device's surface analyzer (sharp stylus) records all peaks and recesses and traces the profile of surface irregularities (Figure 3).

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Figure 3: Roughness tester

3. Results

Statistical analysis SPSS version 26 was utilized for all measurements, and it started with the descriptive statistics as in Table 2 and Figures 4 and 5, which display the mean and standard deviation of compressive strength and surface roughness values for each group. The results indicated that group B (107 MPA) exhibited the highest mean compressive strength, followed by groups C (103.43 MPA) and D (98.43 MPA). In contrast, group A (74 MPA) demonstrated the lowest mean value. In terms of surface roughness, group B exhibited the highest mean value of 3.220, followed by groups C (2.413) and D (2.359). Group A achieved the lowest mean value of 1.451.

Due to the non-normal distribution of the variables, further multiple comparisons across several groups were conducted using the Kruskal–Wallis H-test**,** as shown in Table 3. Additionally, pairwise comparisons between independent groups were conducted using the Mann-Whitney U-test in post hoc analysis.

Table 2: Descriptive Statistics of compressive strength and Surface roughness for all groups

Studied groups	Compressive strength (MPA)				Surface roughness		
	GROUPS	N	Mean	±SD	N	Mean	±SD
Control	Group A	7	74	4.163	7	1.451	.0732
Particles Size 80µm	Group B	7	107	3.742	7	3.220	.0135
Particles Size 70 µm	Group C	7	103.43	5.192	7	2.413	.0183
Particles Size 50 µm	Group D	7	98.43	7.323	7	2.359	.0765

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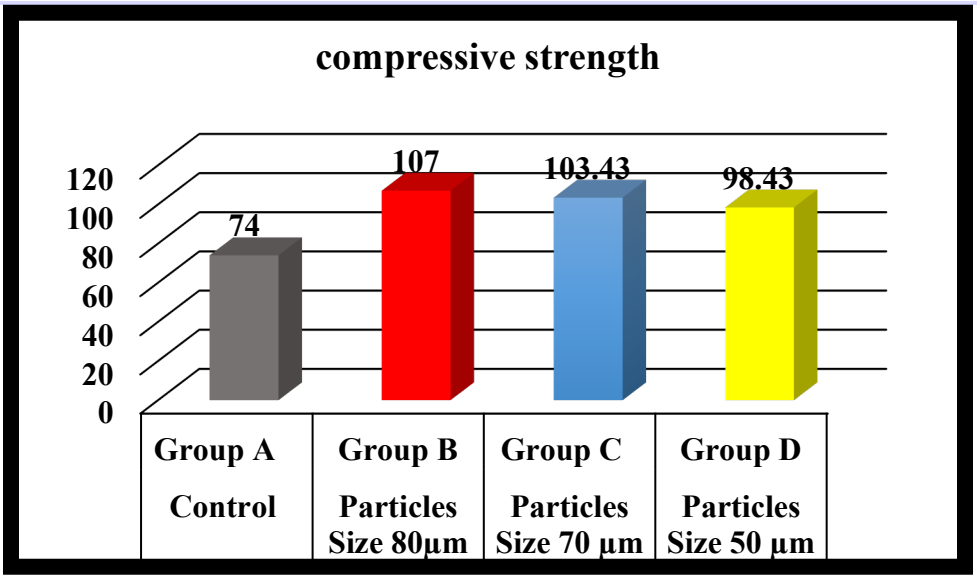

Figure 4: Bar chart showing the mean values of the compressive strength in studied groups.

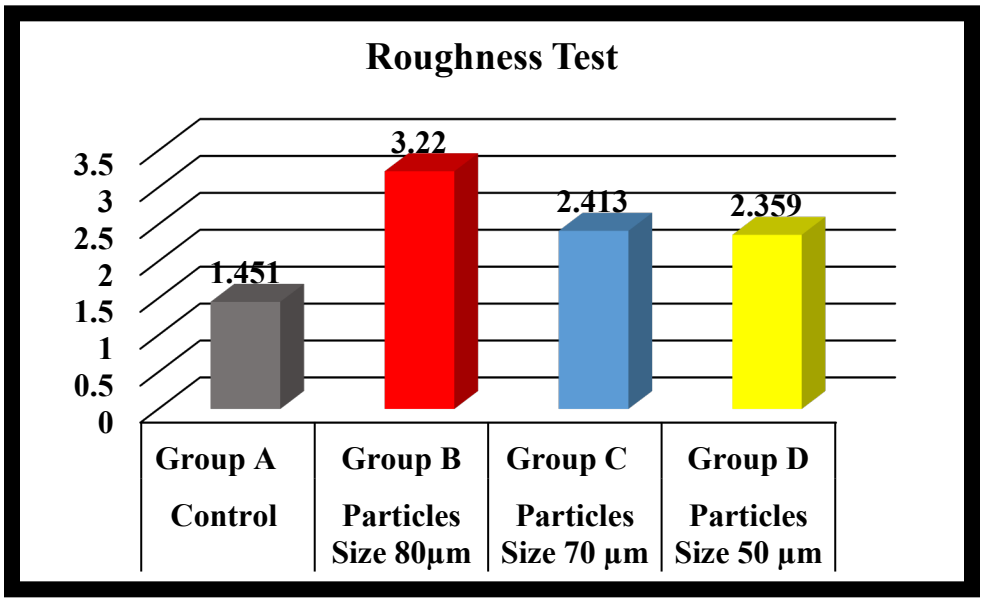

Figure 5: Bar chart showing the mean values of the Roughness test in the studied groups.

Table 3: Test of normality for compressive strength test and roughness test

Tests of Normality						
Test	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Compressive strength test	0.189	28	0.012	0.837	28	0.001
Roughness test	0.191	28	0.01	0.849	28	0.001

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a. Lilliefors Significance Correction
Df: degree of freedom

The Kruskal-Walli's test H revealed a statistically significant difference in compressive strength among the four groups (H= 22.899, p < 0.000*) as in Table 4. Post-hoc (Mann-Whitney U) test was conducted to determine which groups differed significantly. The results as in Table 6 indicate statistically significant differences in compressive strength between group A and each of groups B, C, and D (all p < 0.02. However, there was no distinct statistically significant variation in compressive strength between groups C and B (p = 0.747). The difference between groups C and D was statistically significant (p < 0.002).

The four groups (A, B, C, and D; H= 25.387, p < 0.000*) had significantly different levels of roughness, according to Kruskal-Wallis's H test, as shown in Table 5. Group A's mean roughness (1.451) as in Table 2 was substantially lower than that of groups B, C, and D. All (p <0.02), according to the post-hoc (Mann-Whitney U) test shown in Table 7. Significant differences were also found in all pairwise comparisons between groups B, C, and D (all p < 0.02).

Table 4: Kruskal-Wallis H test of the study sample for the compressive strength test

Studied groups	N	Mean Rank	Kruskal-Wallis test	P-value
Control (A)	7	4.00	22.899	0.000*
Particles Size 80µm (B)	7	21.86		
Particles Size 70 µm(C)	7	21.14		
Particles Size 50 µm(D)	7	11.00		

* Significant between groups using Kruskal-Wallis test

Table 5: Kruskal-Wallis H test of the study sample for the roughness test

Studied groups	N	Mean Rank	Kruskal-Wallis test	P-value
Control (A)	7	4.00	25.387	0.000*
Particles Size 80µm(B)	7	25.00		
Particles Size 70 µm (C)	7	11.00		
Particles Size 50 µm (D)	7	18.00		

* Significant between groups using Kruskal-Wallis test

Table 6: Post-hoc (Mann-Whitney U) for numerous compressive strength comparisons between study groups.

Groups	*P*-Value	Sig.

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Group A	**B**	**0.02**	**(HS)**
	C	**0.02**	**(HS)**
	D	**0.02**	**(HS)**
Group B	**C**	**0.747**	**(NS)**
	D	**0.02**	**(HS)**
Group C	**D**	**0.02**	**(HS)**

* statistical significance for the study group, p-value < 0.05

Table 7: Post-hoc (Mann-Whitney U) for numerous roughness test comparisons between study groups.

Groups		***P*-Value**	**Sig.**
Group A	**B**	**0.02**	**(HS)**
	C	**0.02**	**(HS)**
	D	**0.02**	**(HS)**
Group B	**C**	**0.02**	**(HS)**
	D	**0.02**	**(HS)**
Group C	**D**	**0.02**	**(HS)**

*statistical significance for the study group، p-value < 0.05

4. Discussion

Acrylic dental prosthesis has gained popularity to improve the lives of those who are toothless. However, because of their poor mechanical qualities, these prostheses have disadvantages, such as being prone to fractures and deformations (Habibah et al., 2018). Researchers are investigating a variety of methods to improve the mechanical properties of acrylic prosthesis, involving the application of nanoparticles and the addition of reinforcing components like fibers and fillers. Integrating hydroxyapatite (HA) as filler to PMMA acrylic material is one such technique that frequently improves the material's mechanical qualities. Using HA as a filler increased the flexural strength and elastic modulus of PMMA, according to a study by Habibah et al. (2018) (Habibah et al., 2018). However, it was demonstrated that the mechanical properties of acrylic resin were significantly affected by the amount, size, and distribution of HA particles in the polymer matrix as well as the strength of the bond at the interface (Karadi and Hussein, 2017). All experimental groups in this study received HA at a concentration of 5%, except for the control group, which did not get any additional HA. The findings showed a significant rise in compressive strength. The result of the current study followed a previous research work by Salih et al. (2015), in which adding HA nanoparticles to PMMA resin enhanced its fatigue and compression

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strengths in comparison to unmodified PMMA (Salih, Oleiwi, and Q.A. Hamad, 2015). Likewise, Kul et al. (2016) discovered that the incorporation of HA nanoparticles into PMMA acrylic improved its compressive strengths and thermal conductivity in comparison to PMMA (Kul et al., 2016). This can be ascribed to the compressive strength of HA particles, which is significantly higher than PMMA resin. As a result, the compressive strength of the hybrid composite specimens increased (Salih, Oleiwi, and Q.A. Hamad, 2015). Moreover, increasing the amount of HA filler will significantly affect the mechanical properties. Zebarjad et al. (2011) investigated how HA nanoparticles affected the mechanical characteristics of PMMA nanocomposites using wear tests, compression tests, and three-point bending tests. According to their findings, samples tested in ambient and artificial saliva environments exhibited lower wear rates when the amount of HA filler was increased. Compression experiments specifically showed that adding 2.5% HA filler to PMMA increased its definitive compressive and yield strengths (SM and Ebrahimi, 2011). In the current investigation, compared to unfilled PMMA or formulations with 5% nanohydroxyapatite at smaller particle sizes (70µm and 50µm), there was a notable increase in surface roughness when 5% nanohydroxyapatite (with an 80µm particle size) was added to PMMA. Yet, this alteration is insignificant since high surface roughness might result in significant bacterial colonization (Georgakopoulos-Soares et al., 2023). This outcome is consistent with a study by Karadi and Hussein (2017), which found that adding 2% hydroxyapatite nanoparticles significantly increased impact strength, surface hardness, water sorption, and solubility, but also significantly decreased transverse strength and increased surface irregularity (Karadi and Hussein, 2017). As with any inorganic filler, the mechanical characteristics of PMMA/HA composites may be limited by the inappropriateness between the PMMA and HA (Karadi and Hussein, 2017). Polymeric compatibilizers and coupling agents can help increase the interaction and adherence of organic PMMA matrix and inorganic HA particles (Tham, Chow and Ishak, (2010). Since the preparation of PMMA/HA composite was done without the application of coupling agent in this study. We believe that the increased in surface roughness is due to weakly bonded area and poor interfacial adhesion between the hydrophilic HA filler and the hydrophobic PMMA.

The findings of this study demonstrate that incorporating powdered ostrich eggs as nanofiller materials significantly enhanced the compressive strength and surface roughness of PMMA denture base material. We recommend conducting additional tests, such as impact, fatigue, and fracture testing, to further explore the effects of ostrich egg nanofillers on material properties and advance their potential applications in dentistry and dental manufacturing.

Conclusion:

1. In comparison to specimens devoid of hydroxyapatite (control group), the roughness of the surface and compressive strength of heat-cured acrylic resin increased with the addition of hydroxyapatite.

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2. The specimens' compressive strength increased as the particle size of hydroxyapatite increased, and Group B, consisting of 80m Hydroxyapatite, showed the roughest surface.

Supplementary Material

None.

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Data Availability Statement

Data are available from the authors upon reasonable request.

Conflict of interest

The authors reported that they have no conflicts of interest.

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