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Turning Waste into Strength: Mechanical Evaluation of Glass Ionomer Cement Reinforced with Eggshell Powder

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Abstract:

- ***Background:***

Glass Ionomer Cement (GIC) is a widely used restorative material owing to its chemical adhesion to tooth structure, fluoride release, and biocompatibility. However, its limited mechanical strength restricts its application in stress-bearing areas. Chicken eggshell powder (CESP), a natural biowaste rich in calcium carbonate, has shown potential to enhance mechanical properties of dental materials. This study aims to evaluate the effect of incorporating 5% and 7% CESP by weight into GIC on its compressive strength and surface hardness.

- ***Methods:***

An in-vitro study was conducted with 45 samples divided into three groups: Group 1 (control – GIC without CESP), Group 2 (GIC with 5% CESP), and Group 3 (GIC with 7% CESP). Eggshells were cleaned, powdered, and calcined at 500°C to obtain CESP. The specimens were prepared in standardized acrylic blocks and tested after 24 hours of incubation at 37°C. Compressive strength was measured using a universal testing machine, and surface hardness was evaluated using a Vickers microhardness tester.

- ***Results:***

Group 2 showed significantly higher compressive strength than Groups 1 and 3, while Group 3 exhibited the highest surface hardness. Statistical analysis revealed highly significant differences ($p < 0.001$).

- ***Conclusion:***

Incorporation of 5% CESP improves compressive strength, while 7% enhances surface hardness, making CESP a promising biofiller for reinforcing GIC.

***Keywords**: Glass Ionomer Cement (GIC), Chicken Eggshell Powder (CESP), Compressive Strength, Vickers Hardness, Biofiller, and Calcium Carbonate.*

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I. INTRODUCTION

The introduction of GIC was done in the year 1972 and ever since it has been very popular among the clinicians due to its peculiar properties such as moisture insensitivity, chemical adhesion to mineralized tissues and low coefficient of thermal expansion which is the same as that of the tooth structure. The additional superior properties of GIC includes biocompatibility, fluoride release and rechargeability which are responsible for its anticariogenic properties.

Despite of having numerous advantages GIC has low mechanical strength properties that is responsible for the compromise in its durability in the stress bearing areas.[1]

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Several attempts have been made to improve the mechanical properties of conventional GIC such as by the addition of resin[2] and also by incorporating alumina, carbon, glass, hydroxyapatite and fluorapatite nanoparticles without compromising the fluoride releasing properties of GIC.[3]

Chicken egg shell powder is a low cost, natural and readily available waste product of the food industry, which makes it an extremely cost efficient option.[4]

Chicken eggshell powder (CESP) is composed of 98.2% calcium carbonate, 0.9% magnesium,and 0.9% phosphate, approximately; which is why it is considered a rich source of mineral salts, mainly calcium carbonate.[5]

For this very reason there have been studies which had been successfully conducted in the use of this calcium source in remineralisation of early enamel lesions.[6]

The utilization of CESP as a filler material to enhance the mechanical properties of GI has some advantages, as it is naturally renewable, low-cost, and readily available. Therefore, the present study aims to evaluate these parameters by incorporating CESP at weight percentages of 3% and 5% to the cement powder.

➢ *Aim of the Study:*

To evaluate the mechanical properties of GIC on addition of 5% and 7% wt. chicken egg shell powder.

➢ *Objectives of the Study:*

- To evaluate the mechanical properties of GIC on addition of 5% wt. chicken egg shell powder.
- To evaluate the mechanical properties of GIC on addition of 7% wt. chicken egg shell powder
- To evaluate the mechanical properties of GIC without the addition of chicken egg shell powder.

II. METHODOLOGY

➢ *Sample Size: Total sample size n = 45*

- *Sample Size Calculation*

$$N = \frac{2\,[Z\alpha + Z\beta]2\ S2}{d2}$$

Where $Z\alpha$ =1.96 at 95% confidence level And $Z\beta$ =1.28 at 90% power

S= combined standard deviation and d= Mean difference

d=13.62 s=11.6

Sample size= 15 each group

➢ *Sampling Techique: Convenience Sampling.*

- *Armamentarium and Materials:*

Fig 1 GIC (Shofu Hy-Bond Glassionomer CX Cement)

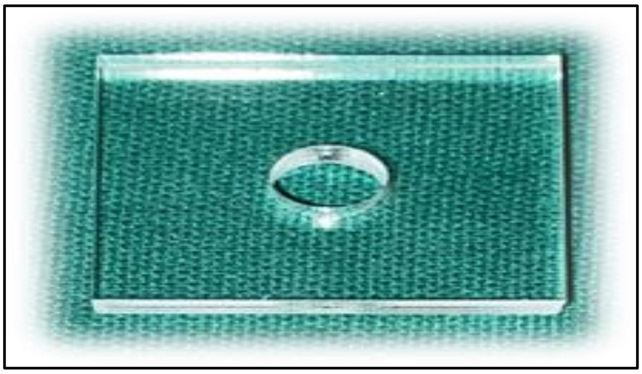
Fig 2 Acrylic Block, 25mm Length and 25mm Width


Fig 3 Chicken Egg Shell Powder, 5% and 7% WT.

Fig 4 Muffle Furnace at 500 Degree Celsius

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Fig 5 200g Weight

- *PTFE Tape (POLYTETRAFLUOROETHYLENE)*

Fig 6 Motar and Pestle

- *Universal Testing Machine*

- *Vickers Microhardness Tester Machine*

- *Egg Shell Powder Preparation*

Twelve chicken eggs will be cleaned with distilled water and kept in hot boiling water for 10 min at 100◦C to facilitate the removal of membranes. The egg shells will be then dried in an oven at 90 degrees Celsius, overnight. The egg shells will be crushed and powdered to small particles with sterile mortar and pestle (Fig 6). Subsequently, it was then kept in a muffle furnace at 500◦C for 3 hours to make sure the resulting powder was pathogen free (Fig 4). GIC will be mixed according to the manufacturer's instructions, with 1:1 (Powder: Liquid), and CESP will be added to the powder component with proportions of 5% and 7% by weight.

Samples will be fabricated using Acrylic block, 25-mm width and 25-mm height (Fig 2) for the compressive strength and microhardness test. A hole of 6 mm diameter will be drilled in order to receive the cement.

The acrylic blocks will be filled with the material, covered with PTFE tape and glass slides, flattened, and pressed in order to eliminate air bubbles from unset cement paste. A 200-g weight (Fig 5) will be placed on top of the set, thus standardizing the pressure exerted during the initial setting of the material. The samples will be ejected from the tubes after 30 min and stored in deionized water at 37 °C and 100% humidity for 23 h in an incubator until testing time.

The specimens will then be divided into 3 groups

- ✓ *GROUP 1 (n =)*
  The Acrylic block received GIC without CESP

- ✓ *GROUP 2 (n =)*
  The Acrylic block received GIC with 5% wt. CESP added to the powder component

- ✓ *GROUP 3 (n =)*
  The Acrylic block received GIC with 7% wt. CESP added to the powder component

Compressive bond strength will be measured using a Universal testing machine with a cross head speed of 1mm per min. The point at which fracture occurs will be recorded in Newton and converted to MPa.

Microhardness will be measured using a Vickers microhardness tester machine (Fig 8). Three indentations will be carried out for each specimen at 25g force for 30s, and the average score of the three readings will be recorded for each specimen.

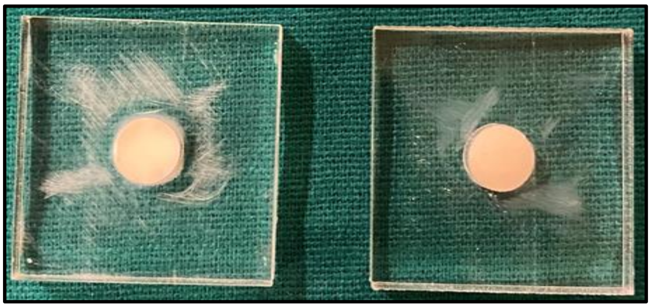

Fig 7 Acryric Blocks Which Received Chicken Egg Shell Powder Added to GIC

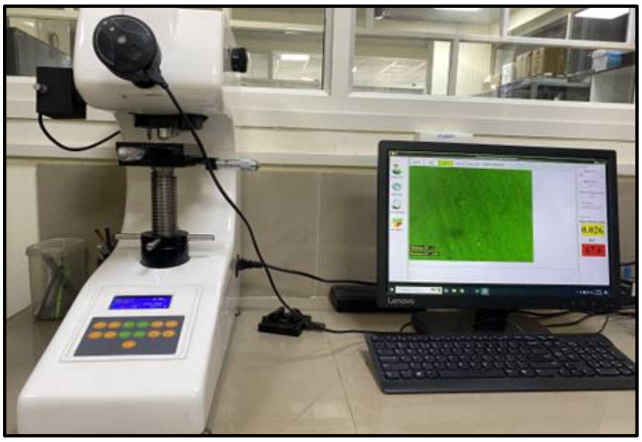

Fig 8 Sample Tested for Vickers Hardness

- *Statistical Analysis*

With 95% confidence level and 90% power wrt (The Role of Chicken Egg-Shell Nano-Hydroxyapatite as Fillers on the Surface Hardness of Glass Ionomer Cement by

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Muhammad Chair Effendia) sample size comes to be 15 in each group (15 x 3 = 45) d=13.62 s=11.6

Data analysis: Analysis will be done by descriptive statistics. Comparison between the groups will be done by ANOVA or Kruskal- wallis test after deciding about the normality of the test. A statistical package SPSS Vers. 25.0 will be used to do the analysis. P<0.05 will be considered as significant.

III. RESULTS

Table 1 Test of Normality

Tests of Normality							
	Group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Comprahensive srength	GIC without egg shell powder	.177	15	.200	.913	15	.153
	GIC with 7%ECP	.179	15	.200	.921	15	.201
	GIC with 5%ECP	.135	15	.200	.978	15	.954
Vickers Hardness	GIC without egg shell powder	.135	15	.200	.917	15	.173
	GIC with 5%ECP	.135	15	.200	.945	15	.442
	GIC with 7%ECP	.126	15	.200	.954	15	.584

Table 2 Compressive Strength of the Samples

Compressive strength (Mpa)	N	Mean	Std. Deviation	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
GIC without egg shell powder	15	51.246	2.453	49.887	52.605
GIC with 7%ECP	15	73.214	1.831	72.200	74.228
GIC with 5%ECP	15	66.619	2.247	65.375	67.863

: F=396.564 p<0.001 vhs

Table 3 Multiple Comparisons Between the Compressive Strengths

Multiple Comparisons Tukey HSD				
Dependent Variable	(I) group	(J) group	Mean Difference (I-J)	p
Comprahensive srength	GIC without egg shell powder	GIC with 7%ECP	-21.968	<0.001 vhs
		GIC with 5%ECP	-15.373	<0.001 vhs
	GIC with 7%ECP	GIC with 5%ECP	6.595	<0.001 vhs

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Table 4 Vickers Hardness of the Samples

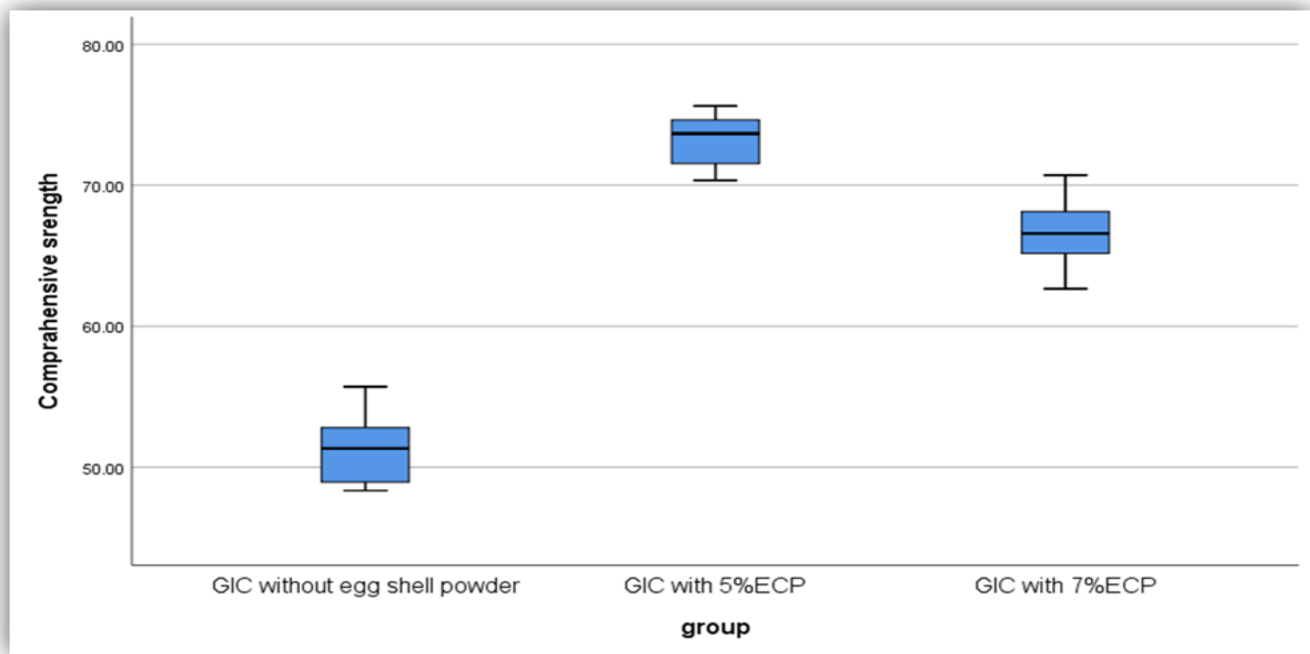
Vickers Hardness					
	N	Mean	Std. Deviation	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
GIC without egg shell powder	15	37.447	1.714	36.497	38.396
GIC with 5%ECP	15	44.860	3.188	43.094	46.626
GIC with 7%ECP	15	57.267	3.499	55.329	59.204

Table 5 Multiple Comparisons of the Vickers Hardness

Multiple Comparisons

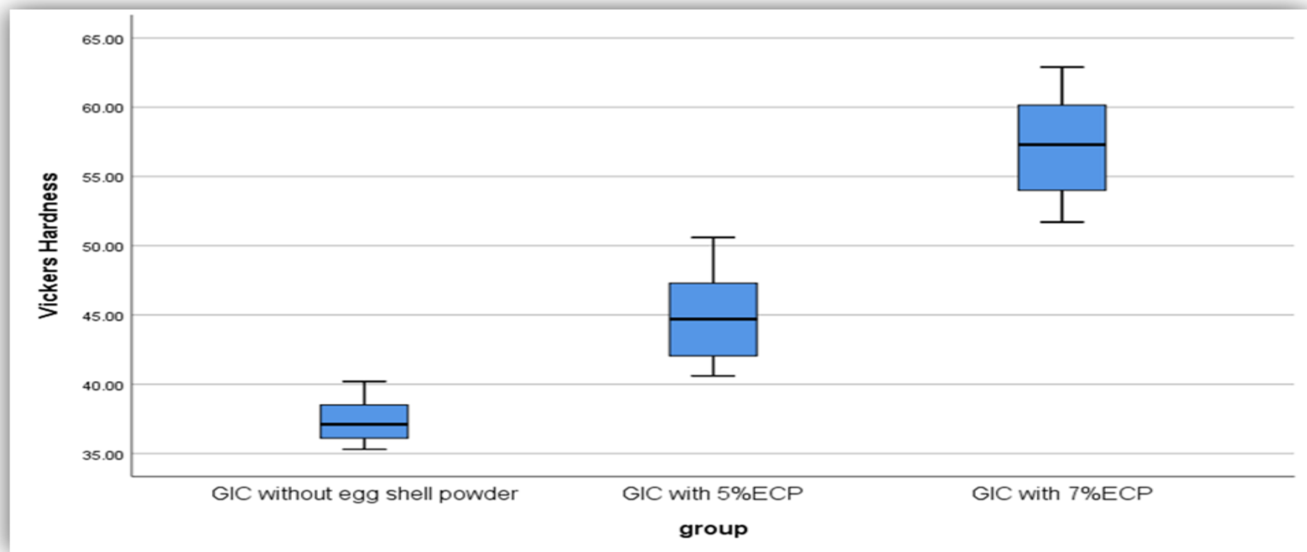
Tukey HSD

Dependent Variable	(I) group	(J) group	Mean Difference (I-J)	p
Vickers Hardness	GIC without egg shell powder	GIC with 5%ECP	-7.413	<0.001 vhs
		GIC with 7%ECP	-19.820	<0.001 vhs
	GIC with 5%ECP	GIC with 7%ECP	-12.407	<0.001 vhs



Graph 1 Compressive Strength of the Samples

The graph shows that the **compressive strength** of GIC significantly increased with the addition of **5% eggshell powder (ECP)** compared to the control group without ECP. However, at **7% ECP**, the compressive strength slightly decreased compared to 5% ECP, suggesting that excessive ECP may negatively affect the material's structural integrity.



Graph 2 Vickers Hardness of the Samples

The graph indicates that **Vickers hardness** of GIC increases progressively with the addition of eggshell powder (ECP), showing the lowest values in the control group and the highest at **7% ECP**. This suggests that higher ECP concentrations significantly enhance the surface hardness of GIC.

IV. DISCUSSION

Glass Ionomer Cement (GIC) is a widely used restorative material introduced by Wilson and Kent in 1972, primarily due to its chemical adhesion to tooth structure, fluoride-releasing ability, and favorable thermal expansion comparable to natural dentition [7]. However, despite these advantages, conventional GIC suffers from inherently low mechanical strength, particularly in terms of compressive and tensile strength, making it less ideal for use in high stress-bearing areas such as posterior restorations [8].

To overcome these limitations, various strategies have been explored to reinforce GIC, such as the inclusion of resin components [9] ,metallic fillers, ceramic particles, hydroxyapatite, and nano-sized bioactive agents [10-12]. Among these, biowaste-derived fillers, especially chicken eggshell powder (CESP**)**, have gained attention due to their high calcium carbonate content (~98.2%) and cost-effectiveness [13]. The present study assessed the influence of incorporating 5% and 7% weight of CESP into conventional GIC powder and evaluated the changes in mechanical properties, specifically compressive strength and Vickers microhardness.

The results clearly showed that both compressive strength **and** surface hardness increased significantly upon addition of CESP. The 5% CESP-modified GIC exhibited the highest compressive strength, significantly outperforming the control (unmodified GIC). This enhancement can be attributed to the bioavailable calcium carbonate in CESP, which likely participated in the setting reaction of GIC. The calcium ions may have improved the matrix density and ionic cross-linking between polyacrylic acid and fluoro aluminosilicate glass particles, thus contributing to the observed mechanical reinforcement [14].

The 7% CESP group, while still superior to the control, showed a slight reduction in compressive strength compared to the 5% group. This suggests that there exists an optimal concentration threshold, beyond which the additive may start interfering with the matrix homogeneity. Excessive filler loading can result in agglomeration of particles, poor dispersion, increased porosity, and impaired acid-base reactions during setting, which in turn reduces bulk strength [15] .Similar trends were reported in the study by Ahmed Mohamed Salem et al. (2022), where higher concentrations of eggshell powder in GIC led to increased solubility and altered physical behavior [16]

Interestingly**,** Vickers microhardness increased progressively with CESP addition, with the 7% group showing the highest hardness values. This suggests that surface hardness may be more tolerant of filler loading than compressive strength, likely due to surface-level reinforcement through mineral deposition and improved packing density [17]. Enhanced surface hardness is clinically significant as it correlates with improved resistance to abrasion and surface wear, thus contributing to better longevity in the oral environment.

The incorporation of CESP as a bio-filler in GIC also aligns with the global shift toward sustainable and eco-friendly biomaterials. Eggshells are a widely available biowaste from the food industry and, when thermally processed, yield a sterile, mineral-rich additive suitable for biomedical use. Studies such as those by Effendi et al. (2021) and Allam & Abd El-Gelee (2018) have confirmed **the** positive influence of nano-hydroxyapatite derived from CESP on GIC's surface hardness and mechanical behavior**,** supporting the current findings [18].

Moreover, the bioactivity of CESP — containing trace minerals like magnesium, phosphate, and strontium — may also promote ion exchange at the tooth-material interface, contributing not only to remineralization but also enhancing the chemical bond to dentin and enamel. Haghgoo et al. (2016) demonstrated remineralization potential of eggshell powder comparable to nano-hydroxyapatite in early enamel lesions, further validating its therapeutic benefits [19].

Despite the promising outcomes, it is important to note that this is an **in-vitro study**, and the mechanical properties observed under controlled conditions may differ in the dynamic oral environment. Factors such as moisture contamination, cyclic loading, and saliva enzymes could affect the clinical performance of CESP-modified GIC. Future studies should evaluate long-term durability, solubility, fluoride release profile, and bonding strength to tooth substrates. Additionally, using nano-sized CESP particles could potentially allow for better dispersion and further improvements in both physical and biological properties.

V. CONCLUSION

The incorporation of chicken eggshell powder into GIC significantly improves its compressive strength and surface hardness. A 5% addition appears optimal for overall mechanical reinforcement, while 7% enhances surface hardness but may slightly compromise bulk strength, highlighting the need for balanced filler loading.

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