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**MECHANICAL PROPERTIES OF GLASS IONOMER CEMENT MODIFIED
 WITH NATURAL NANOSILICA FROM SLOPENG BEACH SAND: A
 COMPARATIVE STUDY**

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ABSTRACT

Background: Glass Ionomer Cement (GIC) is a restorative material capable of releasing fluoride to protect teeth against the activity of cariogenic bacteria. However, the clinical use of GIC in restorations is limited by its relatively low mechanical strength. The incorporation of nano-silica has been investigated as a potential modification to improve the mechanical properties of GIC, including compressive strength, flexural strength, and microhardness. **Purpose:** This study aims to compare the mechanical strength of conventional GIC combined with synthetic nano-silica, and GIC combined with natural nano-silica from Slopeng Beach sand. **Methods** The study consisted of three material groups, each containing 24 specimens, resulting in a total of 72 specimens. Included 24 conventional GIC (K), 24 GIC modified with natural nanosilica from Slopeng Beach sand (P1), and 24 GIC modified with synthetic nanosilica (P2). **Results:** Compressive Strength Test: K 37.09 ± 16.41 N/mm², P1 63.59 ± 12.78 N/mm², and P2 41.85 ± 18.38 N/mm²; Flexural Strength Test: K 23.67 ± 12.88 N/mm², P1 34.15 ± 10.42 N/mm², and P2 27.26 ± 11.03 N/mm²; Microhardness Test: K 357.25 ± 15.21 HV, P1 415.46 ± 14.42 HV, and P2 389.26 ± 16.34 HV. **Conclusion:** GIC modified with natural nano-silica from Slopeng Beach sand exhibited higher compressive strength, flexural strength, and microhardness than GIC modified with synthetic nano-silica.

Keywords: Compressive strength, Flexural strength, Glass Ionomer Cement, Microhardness, Natural nano-silica

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INTRODUCTION

An ideal restorative material must form reliable marginal adaptation and bonds durably to the cavity walls.¹ Glass Ionomer Cement (GIC) is currently the most commonly used restorative material in dentistry and continues to evolve.² According to a study by Collares et al. (2018), the use of GIC in restorations can lead to several failure, susceptibility to wear from masticatory forces, loss of restoration contour especially on the occlusal surface.³ Additionally, GIC has low compressive strength and high solubility, which can lead to secondary caries, pulp irritation, post-restoration sensitivity, and microleakage.⁴

GIC combined with silica is an excellent innovation for optimizing GIC as a restorative material because it is biocompatible and has low toxicity.⁵ Because it is relatively affordable, silica can be modified into nanoparticles to effectively reduce dental hypersensitivity.⁶ Natural nano-silica derived from Slopeng Beach sand has been synthesized with amorphous structure and particle size ~70 nm. Recent studies have demonstrated that silica from sea sand can be incorporated into GIC to improve its properties, supporting the exploration of natural sources such as Slopeng sand for GIC modification.¹⁵

A good dental material should have a sufficient value of compressive strength.⁸ Compressive strength is among the primary mechanical properties required of dental restorative materials, particularly for posterior tooth restorations that are subjected to significant masticatory forces during the chewing process.^{9,10} A higher compressive strength value its ability to maintain the integrity of the restoration when subjected to occlusal loads.¹¹ Flexural strength is a critical mechanical property in the use of GIC, particularly for posterior restorations, which frequently bear masticatory loads.⁴ During chewing, restorations are subjected to repeated loading that can induce micro-bending in the material. When flexural strength is low, the restoration becomes more susceptible to crack formation, fracture, and eventual failure. Therefore, enhancing the flexural strength of GIC is an important strategy to improve its mechanical performance and extend the clinical durability of the restoration.

Microhardness measures a material's resistance to indentation, abrasion, and scratching. In the oral environment, adequate surface microhardness is essential for maintaining the surface integrity and wear resistance of GIC during mastication. Therefore, compressive strength, flexural strength, and microhardness are key mechanical parameters for evaluating the effect of nano-silica modification on GIC, with higher microhardness indicating better surface stability during clinical use.⁴

Scanning Electron Microscopy (SEM) is an electron microscopy technique used to examine surface morphology, porosity, particle size, and the interaction of restorative materials with dental tissue at the micro- to nanoscale. SEM visualizes microstructures beyond the resolution of optical microscopes, including mechanical retention, pore distribution, and surface topography of GIC after laboratory treatments.¹² However, SEM observations don't directly measure mechanical properties and should therefore be interpreted as supporting morphological and microstructural evidence rather than as an independent mechanical outcome. This approach is also relevant to the Sustainable Development Goals, particularly SDG 3 (Good Health and Well-Being) by supporting the development of improved restorative dental materials, and SDG 12 (Responsible Consumption and Production) through the exploration of naturally derived silica from local resources for biomaterial modification.

Based on these considerations, this study aimed to compare the compressive strength, flexural strength, and microhardness of conventional GIC, GIC modified with synthetic nano-silica, and GIC modified with natural nano-silica derived from Slopeng Beach sand. SEM analysis was performed as a supplementary evaluation to describe the surface morphology and microstructural characteristics of the tested materials.

MATERIALS AND METHODS

Study Design and Material

This was an experimental laboratory study using a posttest-only control-group design. The mechanical evaluation of the modified GIC was conducted with reference to ISO 9917-1:2025. The study consisted of 3 material groups, each containing 24 specimens, resulting in a total of 72 specimens, including 24 samples of GIC (K), 24 samples of GIC combined with natural nano-silica from Slopeng Beach sand (P1), and 24 samples of GIC combined with synthetic nano-silica (P2). This study has received ethical approval under certificate no: EC/022/KEPK-FKGUHT/VII/2026. The material used in this study including, glass ionomer cement (Fuji IX, GC, Japan) and nanosilica synthetic (S5130-100G Silica, fumed powder).

Methods

Synthesis of 3% Nano-Silica from Beach Sand

Beach sand from Slopeng Beach was milled using High Energy Milling (HEM) with alumina balls to reduce particle size. The milled sand was immersed in 100 mL of 2 M HCl for 12 h to extract silica and remove contaminants, then washed with distilled water and oven-dried. The dried powder was dissolved in 7 M NaOH to form sodium silicate (Na_2SiO_3), which was titrated with 2 M HCl to pH 6–7 to produce silica gel. The gel was rinsed with distilled water to remove reaction salts and dried at 120°C for 4 h.

Specimen preparation

GIC specimens were prepared following the manufacturer's instructions: powder was divided into two equal portions and incrementally mixed into the liquid on a paper pad using a cement spatula for 30–40 s until homogeneous. A 1:1 powder-to-liquid ratio by weight was used, consistent with the recommended ratio for

conventional restorative GIC. The cement paste was placed into a mould in a single increment with a plastic filling instrument and covered with a celluloid strip. After the conditioning period, the excess material was removed and the specimen surfaces were finished using polishing disc. The specimens were polished until a flat and uniform testing surface was obtained.

Compressive Strength Test

Compressive strength was evaluated using a Shimadzu AGS-X5kN Universal Testing Machine (UTM). Specimens were centered between the compression platens for axial loading at a crosshead speed of 0.5 mm/min. The 1 kN setting indicated the load-cell range, not a maximum load or stopping criterion; each specimen was loaded continuously until fracture, with the machine automatically reducing pressure upon failure. The maximum force at fracture was recorded and used in the formula $CS = P / \pi r^2$, where CS is compressive strength (MPa), P is the fracture load (N), $\pi = 3.14$, and r is the cylinder radius (mm).

Flexural Strength Test

Flexural strength was assessed using a three-point bending test on the Universal Testing Machine (UTM), Shimadzu model AGS-X5kN. The specimens measured 6 mm in width and 4 mm in thickness, with a support span of 10 mm, the crosshead oriented perpendicular to specimen width and advancing at a constant speed of 1 mm/min until fracture occurred.

Microhardness Test

A Micro Vickers Hardness Tester (18-One) was used in this study. A load of 0.05 N was applied for 15 s using a diamond indenter. The indentations were also positioned sufficiently far from the specimen edge. Published dental-material protocols have used three indentations per specimen, with spacing of approximately 0.5 mm, depending on the specimen geometry and indentation size. The resulting indentation visible as a diamond or rhombus shape under 400× magnification was measured diagonally using the ocular lens or monitor display, and surface hardness values were recorded in Vickers Hardness Number (VHN).

RESULTS

Compressive Strength Test

The following table presents the mean of compressive strength values and standard deviations obtained from UTM testing at the Biomaterial Laboratory, Universitas Hang Tuah, Surabaya. The result shown that P1 group had the highest value of compressive strength ($63.59 \pm 12.78 \text{ N/mm}^2$).

Table 1. Compressive strength values and standard deviations

Group	Mean $\pm$ Std. Dev. (N/mm^2)
K	37.09 ± 16.41
P1	63.59 ± 12.78
P2	41.85 ± 18.38

K : Control group GIC without nano-silica addition

P1 : Group 1 GIC with natural nano-silica

P2 : Group 2 GIC with synthetic nano-silica

The result then analyzed statistically with post hoc LSD. LSD P value group P1 indicated significantly difference with group K and P2, $p=0.021$ and 0.017 consecutively. However, the P value between group K and P2 is 0.172 that indicated that there is no difference significantly between that group.

Table 2. P values of LSD post-hoc between groups of Compressive strength test

Group	K	P1	P2
K		0,021*	0,172
P1	0,021*		0,017*
P2	0,172	0,017*	

Flexural Strength Test

Based on the results of a study using the UTM instrument on the control GIC group and the nano-silica-combined GIC group, as reported at , the mean values and standard deviations for each sample are shown in the table 3.

Table 3. Flexural strength values and standard deviations

Group	Mean $\pm$ Std. Dev. (N/mm ²)
K	23.6724 $\pm$ 12.88447
P1	34.1500 $\pm$ 10.42836
P2	27.2653 $\pm$ 11.03404

Table 4. P values of LSD post-hoc between groups of flexural strength test

Group	K	P1	P2
K		0,009*	0,202
P1	0,009*		0,007*
P2	0,202	0,007*	

The results of the study showed a significant difference in the increase in flexural strength between the control group (K) and group P1, as well as between group P1 and group P2. However, there was no significant difference in the increase in flexural strength between the control group (K) and group P2. The flexural strength of the GIC combined with natural nano-silica from Slopeng Beach sand was better than that of the control GIC and the GIC combined with synthetic nano-silica.

Microhardness Test

Based on microhardness testing using a Vickers microhardness tester on the control GIC group and the GIC group combined with nano-silica, the research results showing the mean values and standard deviations of each sample can be seen in the table 5 below.

Table 5. Microhardness values and standard deviations

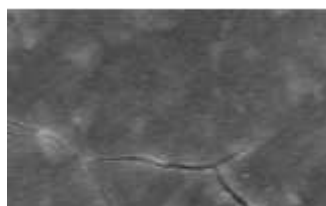
Group	Mean $\pm$ Std. Deviation (HV)
K	357.25 $\pm$ 15.21
P1	415.46 $\pm$ 14.42
P2	389,26 $\pm$ 16,34

Table 6. P values of LSD post-hoc between groups of microhardness test

Group	K	P1	P2
K		0,006*	0,267
P1	0,006*		0,003*
P2	0,267	0,003*	

The results of the study showed a significant difference in the increase in *microhardness* between the control group (K) and group P1, as well as between group P1 and group P2. However, there was no significant difference in the increase in *microhardness* between the control group (K) and group P2. The *microhardness* of the GIC combined with natural nano-silica from Slopeng Beach sand was better than that of the control GIC and the GIC combined with synthetic nano-silica.

Scanning Electron Microscopy (SEM) Analysis

**Figure 1.** SEM at 3500x magnification, nano-silica from Slopeng Beach sand (P1)

SEM analysis was performed as a supplementary technique to characterize the surface morphology and microstructural features of the GIC specimens. At 3500× magnification, the P1 group, consisting of GIC modified with natural nanosilica derived from Slopeng Beach sand, showed a relatively homogeneous surface with small visible cracks.

DISCUSSION

Glass Ionomer Cement (GIC) is a dental restorative material containing 24.9% silica, which provides high hardness and acid resistance.¹³ Silica derived from Slopeng Beach sand has been reported to have a high silica content of approximately 98.9%.¹⁴ The compressive-strength results showed that P1 had the highest mean value, followed by P2 and K. Nanosilica can fill gaps between the polyacid matrix and glass particles, producing a denser structure, reducing porosity, and limiting fracture initiation. Nanosilica particles have a very small size and a large surface area, enabling them to fill the voids between the polyacid matrix and glass particles in the GIC. This results in a denser, more homogeneous material structure and reduces the formation of porosity, which can serve as an initiation point for fractures.^{13,15} The superior performance of P1 may be related to its particle size, distribution, and silica characteristics, which may enhance bonding with the GIC matrix.

The flexural-strength results showed a similar trend, with the GIC containing Slopeng Beach sand nanosilica achieving the highest value. Its nanosized particles and large surface area may effectively fill spaces within the GIC matrix, strengthen bonding between the polyacrylate matrix and glass particles, and reduce porosity and microvoids, thereby hindering crack propagation during flexural loading.^{16,17} Additionally, the homogeneous distribution of nanoparticles reduces porosity and microvoids in the material.¹⁸

The microhardness results showed that P1 achieved the highest score. These results indicate that the addition of natural nanosilica enhances the materials surface resistance to plastic deformation or penetration caused by pressure.¹⁹ A denser matrix reduces the formation of porosity and microvoids, which can act as weak points on the material's surface.²⁰

SEM provided qualitative supplementary information on specimen morphology. The P1 group showed a relatively homogeneous surface with small cracks at 3500× magnification; however, SEM did not quantitatively assess crack size, porosity, particle distribution, or surface homogeneity and therefore cannot independently establish improved mechanical properties or causality.²¹ The extremely small particle size of the nanosilica increases the surface area of contact, thereby enhancing the interaction between the filler particles and the polyacrylic acid matrix in the GIC. This interaction results in a stronger and more compact matrix bond.²²

Within this study's limitations, 3% natural nanosilica from Slopeng Beach sand produced the highest mean compressive strength, flexural strength, and microhardness. Qualitative SEM showed a relatively homogeneous P1 surface with small cracks but did not establish mechanical or clinical superiority. Limitations included the use of one nanosilica concentration, an in vitro design, and qualitative SEM without quantitative microstructural analysis. Further studies should evaluate multiple concentrations, physicochemical properties, aging, bonding, wear, biological response, fluoride release, and clinical performance.

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