MECHANICALLY ENHANCED DENTAL AMALGAMS THROUGH STRATEGIC ZrO_2 MODIFICATION

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Abstract: Dental amalgam fillings are widely utilized in dentistry due to their durability, low cost and ease of manipulation. However, their limitations include creep dimensional change and low strength. Adding ceramic to dental amalgams has been suggested to improve these characteristics. This study evaluated the impact of adding ceramic powders on the mechanical characteristics of dental amalgams. Dental amalgam samples were prepared by adding (0.5, 1, 1.5, 2%wt) different ZrO_2 powders. The specimens were inspected for dimensional change, creep, and compressive strength tests. The findings demonstrated that adding ZrO_2 powders decreased dental amalgam's dimensional change and creep. The addition of ZrO_2 powders demonstrated an increase in dental amalgam's compressive strength, making them a more reliable and durable material for use in dental fillings.

Keywords: Amalgam; strength; ZrO_2; creep; compressive strength; dimensional change

1. Introduction

Tooth decay-related cavities are filled using dental amalgam, a common restorative material. Its unusual metallic composition includes liquid elemental mercury and a powdered silver, tin, and copper alloy [1,2]. About 50% of dental amalgams are elemental mercury. Mercury's chemical characteristics allow it to attach to alloy particles and create a cohesive amalgam [3,4]. Although called "silver fillings" owing to their metallic look, this term misrepresents their material makeup [5]. Dental amalgam, one of the most versatile and durable restorative materials, is utilized in 75% of dental applications [6,7]. With over 165 years of

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experience as a restoration material, it is unmatched in durability and affordability. Dental amalgam is renowned for its capacity to sustain load-bearing stress and provide unsurpassed long-term durability and cost [8,9]. Modern dental restorations need it because of its endurance, self-sealing qualities, and low method sensitivity [10,11].

Because of its mechanical characteristics and affordability, dental amalgam is a flexible and lasting restorative material [12]. Dental amalgam, made of liquid mercury and a powdered alloy like silver, tin, and copper, reacts during setting to generate separate phases [3]. Modern amalgams' high copper content promotes the creation of a copper-tin phase, which resists mechanical deterioration and corrosion, reducing the production of the corrosion-prone gamma-2 phase (Sn-Hg) [13]. This enhancement has extended the lifespan and performance of high-copper amalgams, which have worked well in clinical applications for over a decade, even in massive restorations. Manufacturing technologies like atomization have improved dental amalgam quality and usefulness. The molten alloy is sprayed into an inert gas atmosphere to generate heat-treated spherical particles to improve their characteristics. These advancements increase handling, homogeneity, and consistency, making amalgam from a favored material for clinical situations requiring durable and trustworthy restorations.

Zirconia is famous for ceramics for its ability and hardness to endure typical cracks. The material's tiny grain size, less than a micron, enables excellent surface finishes and sharp edges. Scientists and manufacturers use Y-TZP (zirconia) in sophisticated formulations to avoid fractures [14,15]. Dental research and business have achieved their aims using zirconia ceramics and technological technologies. Zirconia's aesthetics and biocompatibility make it attractive in biomedical applications, especially surgical implants. It is biocompatible and can tolerate the oral cavity's temperature and chemical and mechanical pressures, making it a popular material for veneers, implants, bridges, and crowns. The dental industry has seen a "Big Bang" in zirconia manufacture in the recent decade [16–18]. Previous advancements were discovered by global advancements that made substantial assumptions. Dentists concur that this revolutionary technique takes much time. The dental profession lacks clinical data on zirconia-oriented reconstruction intensity resistance under bonding, color performance, lifespan, and fatigue [19].

With the rising need for durable prosthetic materials in aging populations, zirconia has gained prominence across both dental and orthopedic applications. Its exceptional fracture toughness, low thermal conductivity, resistance to crack propagation, high ionic conductivity, and chemical inertness, coupled with excellent biocompatibility, make it ideal for load-bearing environments [20–22]. Historically, zirconia has been applied in ferrule systems, precision mechanical assemblies, and environmental filtration devices. In orthopedics, it has been employed for over five decades in total hip replacements, particularly in femoral

head components [23]. In dentistry, its use over the past 20 years includes dental abutments, implant frameworks, and bi-layered structures for crowns and bridges [24,25]. The development of translucent, tinted zirconia has further improved aesthetic outcomes, achieving a flexural strength of 900–1400 MPa and a fracture toughness of 6 $MPa \cdot m^{1/2}$ [26]. These enhancements support the fabrication of monolithic crowns and posterior bridges with superior load-bearing performance [27]. Zirconia also exhibits favorable biological and mechanical surface characteristics, including enhanced cell adhesion, bonding strength, bacterial resistance, and wear durability, reinforcing its suitability for long-term biomedical applications.

Surface treatment and machining enable zirconia synthetic bone fillers to repair fractured bones [28]. Its medicinal uses include arthroplasty. For orthopaedical reasons, dental crowns, tibial plates, temporary braces, zirconia, and yttria-supported zirconia are utilized in hip joint heads [29]. Only three zirconia systems are utilized in dentistry. First, there is zirconia-doped alumina (ZTA), next Mg-PSZ, and finally 3Y-TZP [30]. TZP and PSZ are medically safe. However, zirconia toughened alumina (ZTA) bacteria, which reduced joint replacement efficacy and caused long-term infections. Dental restorations with bacterial plaque may worsen gum disease, periodontal disease, and dental cavities [31]. Plaque preservation is linked to restorative chemical roughness and surface energy. Medical study demonstrates that rougher surfaces encourage bacterial colonization. Bacteria often hide in symptom-causing tooth cracks [32].

This works aims to determine and evaluate the impact that occurs on the mechanical characteristics of dental amalgam restorations when ceramic materials are added to them. This study aims to understand how adding ceramic materials affects dental amalgam restorations' strength and elasticity. The mechanical characteristics of dental restorations with and without the addition of ceramic are used to determine whether the addition of ceramic positively affects the mechanical characteristics of dental restorations. This study provides further information and understanding about using ceramics to improve dental amalgam restorations' characteristics. The findings could lead to improved dental amalgam restoration materials, improve the dental restoration process, and increase the sustainability of materials.

2. Experimental Work

Material

A SDI, non-gamma 2 admix dental amalgam 600mg alloy Capsules weight 540mg of Mercury. The alloy/Mercury Ratio (1/0.90) Composition. The alloy powder composed of Ag 40%, Sn 31.3%, and Cu 28.7% was utilized in this study is made in Australia and purchased from the market is the master powder alloy

utilized. ZrO_2 ceramic micron-sized powder of purity 99.99% and 1 to 2 μm powder particle size is added to powder alloy in different percentages (0.5, 1, 1.5 and 2 wt%) as shown in Table 1.

Table 1

Composition of the used samples

Sample	Amalgam (wt.%)	ZrO_2 %
Reference (R)	100	-
Sample 1	99.5	0.5
Sample 2	99	1
Sample 3	98.5	1.5
Sample 4	98	2

Specimens Preparation

Samples were prepared according to ADA specification No.1 [ADA] by pressing the capsules so that the mercury would mix with the powder. Then, the mix was triturated by Amalgamator type for 30 seconds. Then, the capsule opened and ejected the amalgam paste by placing it in the cylindrical mould made from Teflon. Then, the amalgam paste was compressed with a 2 mm condenser tool to fill the cylindrical mould, as demonstrated in Fig. 1. If there is any unreacted mercury (access mercury), it will be squeezed to the top after pressing the filling into the mold with dimensions of 4 mm in diameter and 8 mm in height. The mould is opened, and the specimens are ejected. The specimens have been stored at 37±1 ^oC.

Fig. 1. The shape of the amalgam sample

Microstructure Observation

A specimen is taken after the final setting is completed, cold mounted using polyester resin, and grinded with emery paper in the following sequence (360, 400, 600, 800, 1200, 2000, 3000). It is polished with an alumina Suspension solution of particle size 0.2 μm and tested using an optical microscope. Amalgam specimens were etched using Nital, a solution of nitric acid and alcohol, then rinsed, washed with water, and dried.

Dimensional Change

Measured dimensional alteration Per ADA. Standard No. 1, the first length measurement should be taken 5 minutes after trituration completion. The sample was positioned in a micrometre with an accuracy of 0.1 µm. The samples were unrestrained throughout the test. They were incubated for 24 hours at a constant temperature of 37 ± 1°C. The samples' lengths were subsequently measured again. The ADA standard No. 1 stipulates that the dimensional variation has to be within ± 20 µm/cm for dental amalgam to be deemed acceptable.

Creep

The creep test of amalgam is conducted according to ADA specification No.1 by applying a compressive pressure of 36 MPa to the prepared sample after 7 days of ageing at 37± 1 Cº. The change in length between 1 and 4 hours of the spacemen under the applied load divided by the original length is the creep percentage.

$$\text{Creep Percent } \% = \frac{L_\circ - L}{L_\circ} \times 100 \quad (1)$$

where:
Lo = original length,
L = final length.

Compressive Strength

Compressive tests were carried out with a universal testing machine type WDW 200, China and accomplished according to ADA specification No. 1 [33]. The surfaces of each specimen were planned perpendicular to the axis with 1500 wet silicon carbide emery paper. The first measurement was carried out one hour after the end of trituration; the second was measured after 24 hours. Meanwhile, these specimens were stored at a constant temperature of 37±1ºC till the exam time. The specimen was placed vertically between the jaws, and pressure was applied; the graphic representation for compression strength measurement is that the test was run at a constant loading speed of 0.4 mm/min. The mean value of three specimens of each filling alloy has been reported to the nearest 1 MPa. The following formula is utilized to calculate the compressive strength [33]:

$$\text{Compressive strength (MPa)} = \frac{\text{Max} \cdot force(N)}{\text{cross-sectional.area } (\text{mm}^2)} \quad (2)$$

3. Results And Discussion

Fig. 2 illustrates the reference amalgam microstructure with varying weight percentages of Al_2O_3. The amalgam matrix comprises the γ1 phase (white areas), while the black regions represent the η phase (Cu_6Sn_5), and the dark grey areas are composed of unreacted particles, which include the γ phase (Ag_3Sn) and the ε phase

(Cu_3Sn) [34]. Adding ceramic particles to the amalgam matrix reduces the pore size in the filling, which means that the filling will be denser and less porous. Ceramic particles help distribute amalgam particles more uniformly throughout the filling, improving the filler's mechanical characteristics.

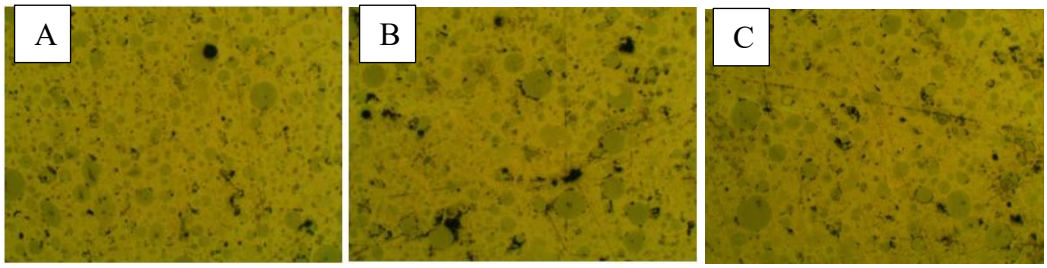


Fig. 2. The microscopic structure of amalgam (reference amalgam At different magnifications: a) 20X, b) 40X, c) 100X

Table 1 demonstrates the creep and dimensional change findings for different percentages of adding ceramic powder. Creep values (0.01-0.57), the percentage of creep allowed by [35]. Creep is a slow change in shape resulting from pressure due to dynamic pressures inside the mouth. Creep causes an amalgam to flow [36].

Creep Percent is calculated by using the following formula [37]

$$\text{Creep Percent } \% = \frac{L_\circ - L}{L_\circ} \times \mathbf{100} \tag{3}$$

where: Lo = original length, L = final length.

Dimensional changes

Dimensional alteration needs to comply with ADA requirements [35]. Dimensional alterations for all amalgams remain below the specified limits (refer to Table 2).

Table 2

The rates of non-dimensional change and creep

Sample	Dimensional change	Creep%
Reference (R)	0.075 0.072	0.54
Sample 1	0.058 0.056	0.25
Sample 2	0.044 0.052	0.16
Sample 3	0.037 0.039	0.16
Sample 4	0.034 0.026	0.1

Dimensional variation is influenced by several variables, including the mercury/alloy proportion and the methods of trituration and densification. Throughout fusion, the reaction undergoes simultaneous expansion and contraction. Gamma particle decay often occurs in constriction, while gamma-1 production induces expansion. Consequently, the overall dimension alteration is the aggregate of these two processes. Consequently, incorrect manipulation that alters the proportion of gamma to gamma-1 and η in the amalgam group will result in dimensional change.

Compression test

It has been noticed from Fig. 3 that the fracture resistance without adding ceramic powder is weak compared to Fig. 4 (A, B, C, D) with ceramic powder added in different proportions. A compression test was conducted on it one hour after its preparation. The higher the percentage of powder, the greater the percentage of fracture resistance for the following reasons: the fracture resistance of amalgam fillings increases when ceramic powder is added due to the increased hardness of amalgam filling. Ceramic powders help improve stress distribution within the amalgam filling. When the insert is subjected to a force, the stress is evenly distributed across the ceramic particles, reducing local stress concentration and preventing fracture.

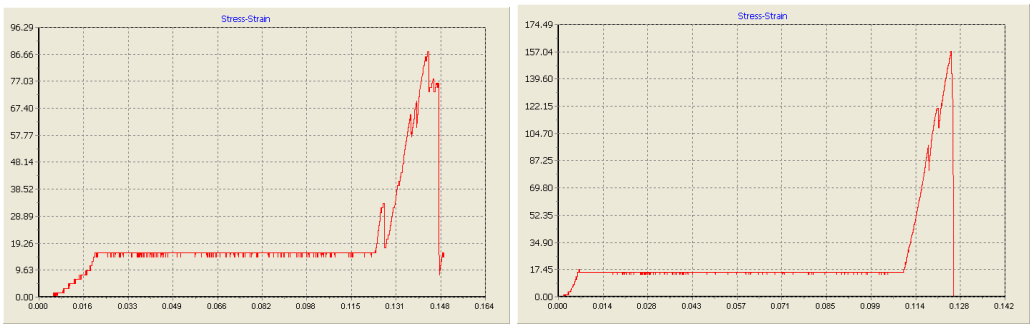
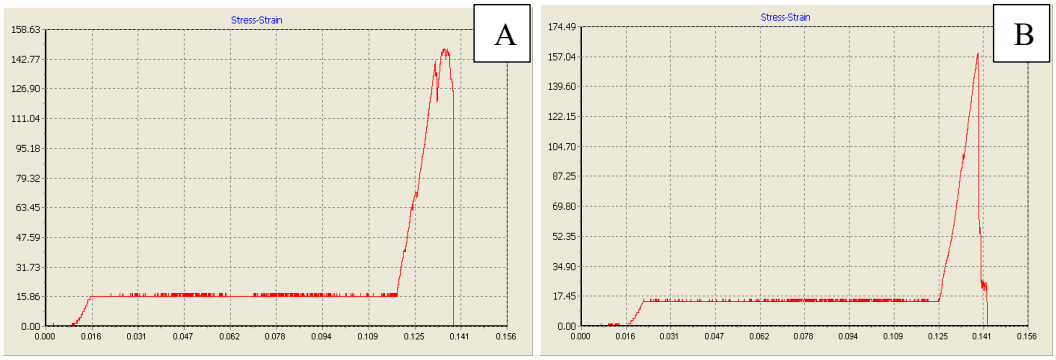


Fig. 3. Breakage resistance for reference sample without adding ceramic powder



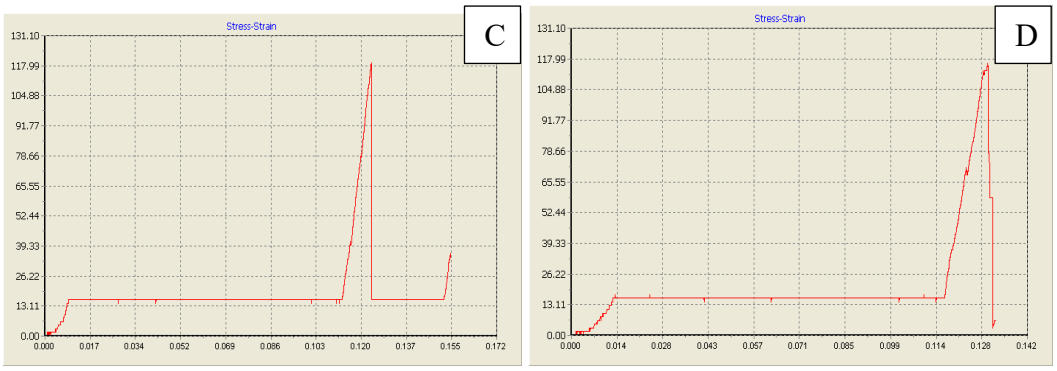


Fig. 4. The fracture resistance after one hour of the amalgam filling with adding different percentages of ceramic powder for (a) sample 1 (b) sample 2 (c) sample 3 (d) sample 4

After 24 hours of preparing the samples, a difference in mechanical characteristics has been noticed. After 24 hours, ceramic-added amalgam fillings harden and become significantly more substantial, generally stronger than traditional amalgam fillings. Amalgam fillings with a ceramic additive that is pressure tested after 24 hours are more resistant to fracture due to the hardening of the filling over time and the increased bond strength between the ceramic particles and the amalgam matrix. It has been noticed in Fig. 5 the fracture resistance before adding the ceramic. It has been also noticed in Fig. 6 that the fracture resistance increases with the percentage of ceramic powder and is much better than the test after one hour.

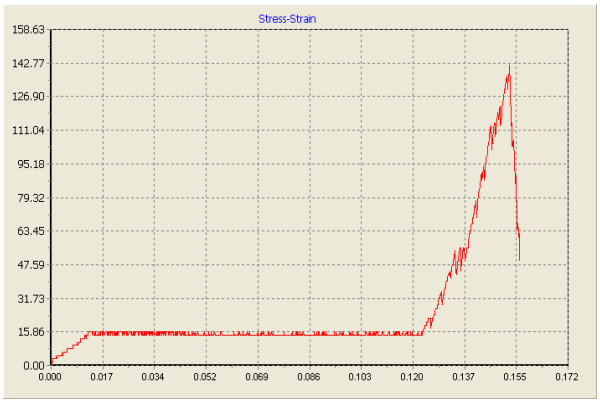


Fig. 5. The fracture resistance of the reference sample at 24 h

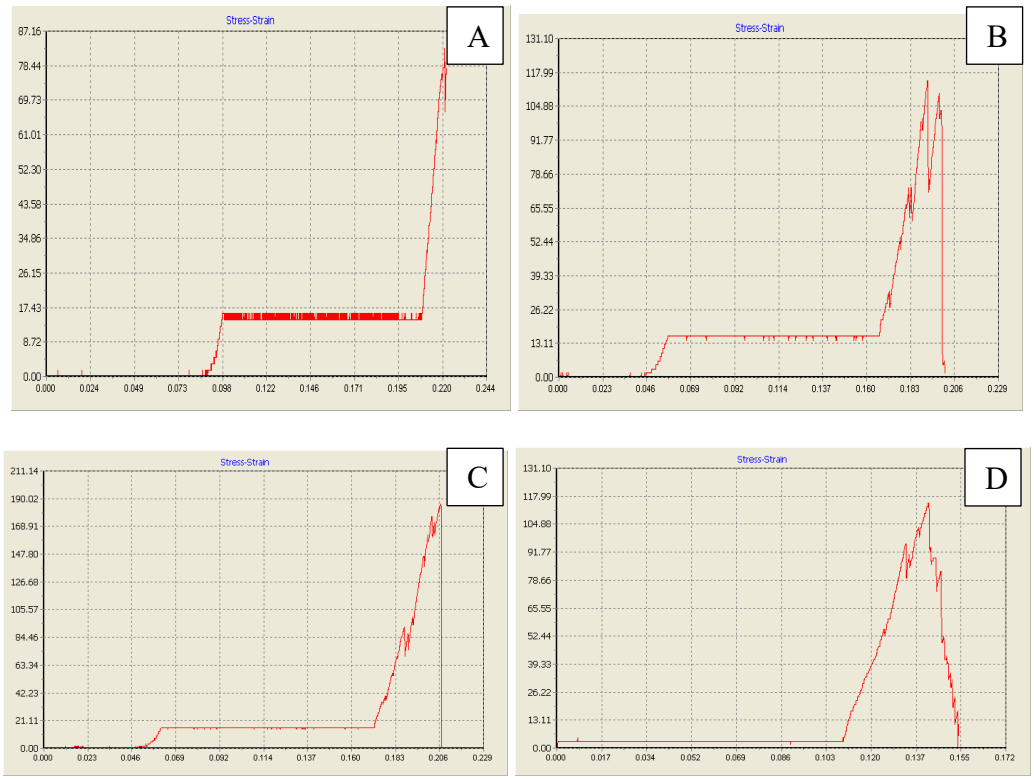


Fig. 6. The fracture resistance after one hour of the amalgam filling with adding different percentages of ceramic powder for (a) sample 1 (b) sample 2 (c) sample 3 (d) sample 4

4. Conclusion

The study effectively highlights the impact of ZrO_2 ceramic powder additions on the mechanical characteristics of dental amalgam restorations. The findings demonstrate that incorporating ceramic powders significantly improves the dimensional stability, creep resistance, and compressive strength of amalgam, thereby addressing some of the material's inherent limitations such as low fracture resistance and susceptibility to deformation under prolonged stress. The inclusion of ZrO_2 powder facilitates a denser and less porous microstructure, enhancing mechanical integrity by improving stress distribution within the amalgam matrix and reducing localized stress concentrations.

Furthermore, the results reveal a correlation between increasing ceramic content and enhanced mechanical performance, with improvements in fracture resistance observed after both one hour and 24 hours of sample preparation. These enhancements are attributed to the hardening effect and stronger bonding between ceramic particles and the amalgam matrix over time. By achieving a balance between material composition and processing techniques, the modified amalgam

exhibits superior durability and reliability for dental applications, particularly in load-bearing scenarios.

Recommendations For Future Works

The first suggestion is to increase the percentage of ceramics. The higher the percentage of ceramics, the better the mechanical characteristics of the amalgam filling. Likewise, the following tests can be utilized: tenacity, hardness, fatigue, and shock tests for amalgam fillings to evaluate their mechanical characteristics and clinical performance.

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