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Compressive Strength and Surface Roughness of Nanoparticles Enriched Glass Ionomer Cement

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Abstract

Aim: This study was assumed to investigate the effect of incorporation of nanoparticles “Titanium Dioxide Nanoparticles (TiO_2)” in two different percentages which are 3% and 5% (by weight) on compressive strength and surface roughness of glass ionomer cement (GIC) so to improve the conventional glass ionomer cement properties.
Materials and Methods: the powder of GIC was incorporated with TiO_2 nanoparticles at two concentrations: 3% and 5% (w/w). An unmodified conventional GIC used as the control group. Ten specimens of each GIC group were used to study the compressive strength using a Universal Testing Machine. Also, 10 discs from each GIC group were used for surface roughness measurement by using profilometer. one way analysis of variance ANOVA test and Tukey’s test were used to analyze data. Results: Nanoparticles incorporation to GIC lead to improve its compressive strength for both percentages 3% and 5%, Tukey’s test showed a significant increase in compressive strength between nanoparticles incorporated and conventional group. The surface roughness measurement also show significantly improvement in both 3% and 5% nanoparticles groups ($p<0.05$). Conclusion: GIC with TiO_2 nanoparticles.

Introduction:

The glass ionomer cement (GIC) consist of powder and a liquid that based on the acid-base reaction between polyalkenoic acid and leachable silicate glass, the mixture of these materials yielded a plastic mass that later solidified into a rigid solid (1). The glass ionomer cement (GIC) first discovered by Wilson and Kent in1972 (2). Since that day it has long history of clinical using as a major restorative filling material used in atraumatic restorative treatment (ART) and restoring cervical caries lesions. GIC is also used in liner and base materials, pits and fissures sealants, luting agents and core building material (3). That due to its respectable properties such as chemical bonding to mineralize tissues, low thermal expansion's coefficient which is close to that of dental tissue, good tissue biocompatibility (4,5) Anti-cariogenic properties as it is capable of absorbing and releasing fluoride (6). However, at the same time, GIC is a brittle material which can't withstand high stress area because of its limitations like low fracture toughness, low wear resistance, low compressive and flexural strength, dissolution on water, increase of the surface roughness by time (3,5,6,7). These GIC's drawbacks may lead to restoration failure as the bacteria can grow that lead to recurrent caries or fracture of the tooth or restoration, especially in high stress bearing area. To overcome these limitations many researchers worked to enhance the mechanical and physical properties through numerous modifications or methods like incorporating additional elements into the traditional GIC materials (8). Nano dentistry is a revolution involve usage of nanoparticles treating and preventing dental diseases and development of materials with improved properties (3), nanoparticles materials is referred to solid insoluble particles with tiny size of 1–100 nm diameter (9). The nanoparticles were incorporating in dental restorative materials manufacturing such as glass ionomer cement and the Glass ionomers with nanoparticles are called Nano ionomers (10). The addition of nanoparticles into the glass powder of GICs improves the material properties by increases the particle distribution and occupy the void or unfilled spaces between GIC particles. The nanoparticles also increasing surface area to volume ratio and this act as reinforcements of the GICs (11). In addition, Nano ionomers is bactericidal, fluoride releasing, pleased aesthetically with higher optical and translucency characteristic than conventional GICs(10) with improve physical and mechanical properties of the hardened restoration than conventional GICs (12,13).

Titanium dioxide (TiO_2) nanoparticles is inorganic reinforcing fillers that added to dental materials due to its chemical stability, non-toxic and biocompatible properties (3,14). In a recent study, Titanium dioxide nanoparticles were added into the powder component of GICs and this was significantly improved the GICs' physical and mechanical characteristics (12,15).

Compressive strength is one of the most crucial mechanical qualities of materials use in atraumatic restorative treatment (ART), as Compressive forces make up the majority of oral forces during mastication, it is essential to confirm that the material's mec hanical qualities are strong enough to tolerate this mastication force. So compressive strength test is frequently use test for evaluate the clinical efficacy of dental materials as it is the ability of a material to withstand the force that led to fractures (16).

Maintaining smooth surfaces that can withstand masticatory forces is one of the most critical factors for restorative materials to maintain their long-term clinical efficacy (17). Rough surfaces accumulate more plaque than smooth surfaces, additionally, the material is easier to wear. An increase in the roughness of restorative materials' surfaces is a precursor to bacterial colonization and a risk factor for developing gingival diseases in the future. Both internal and external factors can affect the surface roughness of dental materials (18).

The aim of the current study was to investigate the impact of adding TiO_2 nanoparticles at different percentage on the compressive strength and surface roughness properties of a conventional glass ionomer material.

Materials and Methods:

The study design assumed to assess the effect of Titanium Dioxide Nanoparticles (TiO_2) incorporation in two percentage on compressive strength and surface roughness of GIC and compared them to the traditional glass ionomer cement (GC Fuji II glass ionomer restorative cement). Titanium dioxide nanoparticles which used in this study had spherical morphological shape, and their partial size was about 10-30um.

Sample grouping

TiO_2 nanoparticles were added to the powder of a normal GIC at two percentages "3% and 5% (w/w)" (3,12,15,19).

The Titanium Dioxide nanoparticles manually combined with glass ionomer powder using a metal spatula on a mixing paper at room temperature (20).

The control group was the normal, unaltered glass ionomer cement GIC for the two tests.

Group 1: control group of conventional glass ionomer.

Group 2: 3% (w/w) TiO_2 nanoparticles incorporated glass ionomer.

Group 3: 5% (w/w) TiO_2 nanoparticles incorporated glass ionomer.

The glass ionomer material's powder liquid ratio was 3:1 g/g, and the mixing procedure was carried out in accordance with the authorized manufacturer recommendations.

Compressive strength assessment

Specimen preparation

Ten cylindrical shaped specimens were made from each glass ionomer group with measurements of (4 mm diameter and 6 mm height) according to ISO 9917-1: 2007 standard (21) by using Teflon mold (22). After setting, the specimens removed from the molds and stored for 24 hours in distilled water at 37^{o} C (11).

Test measurement

The compressive strength (CS) was measured for each specimen after take it from the container and dry it using absorbing paper, then put it in a Universal Testing Machine (GESTER, China) as seen in fig. (1) and apply force with a crosshead speed of about 1 mm/min according to the ISO 9917-1 recommendation (11). The maximum force was recorded in reaching the point of compressive fracture. The greatest force needed to fracture each sample was obtained in newton and the compressive strength was measured in MPa using the next formula: $CS = 4P/\pi D^2$

"As P is the maximum applied force required for specimen fracture in (N) and D is the diameter of the specimen in (mm)".

Surface roughness assessment

Specimen preparation

Ten-disc shaped specimens were prepared from each GIC group with standard measurements of (10mm in diameter and 2 mm in thickness) using special designed mold according to manufacture instructions (23). The mold was put on glass slab, its hole filled with the mixed cement, cement surface was covered with matrix strip of polyester matrix and pressed with a glass slide gently for 1 min. Samples stayed within the matrix for 20 min then immersed in container containing distilled water at 37C°for 24 h before testing.

Test measurement

After take it from the container and dry it with absorbing paper, The surface roughness for each specimen was measured by using profilometer (Taylor-hobson, tylasurf 10/ Leicester, England). Profilometer has A pointed diamond stylus which is used to trace the profile of surface imperfections as seen in fig. (2). The stylus moved at a regular speed of 1mm/s with cut-off value of 0.8 mm and tracing distance of 4.0 mm.

Three readings for each specimen were taken in different directions (horizontal, vertical and oblique) through the target area passing through the center point of the specimen. The mean of three readings was calculated using the arithmetic roughness parameter and expressed in Micrometer (μm) (24).

Statistical analysis
The data then statistically analyzed by SPSS program using Saphiro-Wilk normality test, one-way ANOVA test to identify signification, and A post hoc test was performed using Tukey's HSD test to analyze the significant difference between the groups (11).

Results:

Compressive strength:

Data of compressive strength showed normality, one-way ANOVA test as seen in Table (1) showed statistical difference ($p<.05$) among groups and Tukey test as shown in Table (2) revealed that there is a significant rise in compressive strength for both 3% and 5% (TiO_2) nanoparticles group as compare to control 0% (TiO_2) nanoparticles GIC group. At the same time the 3% (TiO_2) nanoparticles group has higher compressive strength than 5% (TiO_2) nanoparticles group but there is no significant difference ($p>.05$)

Surface roughness:

Surface roughness data also showed normality, the one-way ANOVA test as seen in Table (3) showed a statistical difference ($p<.05$) among groups, and Tukey test as seen in Table (4) showed a significant decrease in surface roughness between the investigated groups. The highest value was found in 5% (TiO_2) nanoparticles group followed by 3% (TiO_2) nanoparticles group and the lowest value was in control group.

Discussion

Compressive strength
The compressive force is the most masticatory forces occurring in the oral cavity. All restorative material should have acceptable compressive strength (CS) to withstand these masticatory forces. The compressive strength of GIC increased significantly after TiO_2 nanoparticles incorporation. This finding was agreed with what found by Abed et al., Mansour *et al*., Ashraf *et al*., and Hamid e*t al* (5,11,14,25).

This can be explained by increasing the particle joining between titanium dioxide and GIC matrix particles because the surface of TiO_2 has rich hydroxyl groups, in addition, the TiO_2 nanoparticles modified GIC powder had a wide range of particle size distributions in which the TiO_2 nanoparticles has small size that able to fill the empty spaces and the voids between macromolecules of GICs. Also, the high density at the nanoparticle's interfaces tend to resist compression, as well as the fact that compressive strength of TiO_2 particles is higher than the glass particles (11, 14,25).
In this study, we found the compressive strength of 5% TiO_2 nanoparticles GIC was lower than that of 3% TiO_2 nanoparticles GIC but this decrease was not significant. This may agree to what find by Elsaka et al., (19) who found that addition of more nanoparticles will decrease the compressive strength and he explain that because TiO_2 nanoparticles have a bigger surface area and a smaller specific size than glass particles. So maybe There is not enough polyacrylic ionomer to effectively attach to that larger volume of TiO_2 nanoparticle powders and, so the interfacial interaction between the particles and the ionomer matrix will be weaker (19).

Surface roughness
In terms of surface roughness, the average height of the surface profile above and below a centerline across a specific sampling length is considered (23). The study of surface roughness is crucial because it influences aesthetics, stain resistance, crack appearance, light reflection, bacterial adhesion and biofilm buildup, all of which can increase the risk of periodontal disease and carious lesions (26). The crucial threshold value for bacterial retention is thought to be a surface roughness value of 0.2 m. Plaque

accumulation would grow with a surface roughness value greater than 0.2 m, increasing the chance of developing caries (17). The parameter that is most usually used to describe surface roughness is average roughness (Ra), which is measured in vitro with a profilometer. It gives two-dimensional data and mathematically determines average roughness (23). The results of the present study revealed that surface roughness of GIC was significantly decreased by the incorporation of TiO_2 nanoparticles, and as the percentage of nanoparticles increased from 3% to 5% the surface roughness was decreased more. This revealed substantial improvements in GIC enriched with TiO_2 nanofillers compared with the traditional GIC (control). This finding can be explained by the fact that the distribution of the cement particles inside the matrix and their interfacial bonding were both impacted by the nanosized particles. Surface with nanoparticles had less porosities and voids compared to traditional surface (27). These results supported by previous researches on nano filled GIC. Soares et al., found that nano filled GIC has surface roughness much lower than conventional one (28). Mohamad et al., discovered that the micro filled GIC had surface roughness higher than nano filled GIC, which mean materials with greater particle sizes have higher values of surface roughness and particle size has a significant impact on how rough the surface of dental materials is (29). It has been suggested that bigger glass particles combined with nanostructures (between 1 and 100 nm in size) may produce an adequate matrix wrap with a more desirable surface roughness than other dental materials in general (3). Therefore, using nanoparticles could result in a surface roughness that is favorable for dental materials.

Conclusion:

With the limitations of this study, it was found that nano filled GIC “with 3% and 5% (w/w) TiO_2 nanoparticles” is a promising material with enhanced both characteristics of compressive strength and surface roughness. However more studies on other characteristics are needed to confirm its effectiveness as a promising material.

Figure 1: Cylindrical specimen put it in a Universal Testing Machine for compressive test.

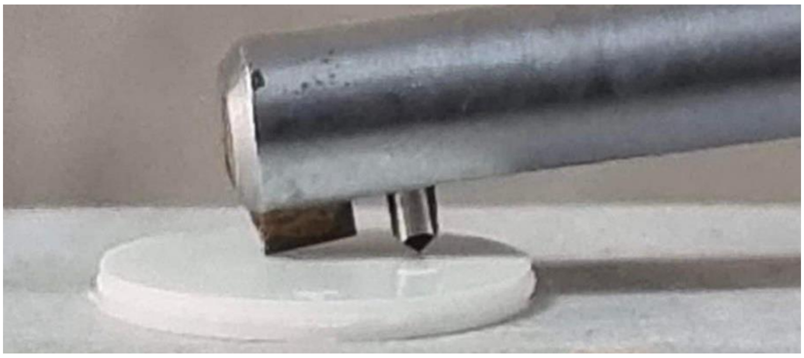

Figure 2: Disc-shaped specimen put in profilometer for roughness test

Table 1: one way ANOVA test for compressive strength

	Sum of Squares	df*	Mean Square	F	Sig.**
Between Groups	3474.961	2	1737.481	7.289	.003
Within Groups	6436.337	27	238.383		
Total	9911.298	29			

* df= degree of freedom

** P< 0.05 mean significant difference exist

Table 2: Tukey analysis of mean ± standard deviation values of Compressive strength in (MPa), subset for alpha= 0.05.

Groups	N	Mean ± SD (MPa)	Tukey grouping*
GIC-control	10	92.751 ± 19.477	A
GIC-3% (w/w) TiO_2	10	118.444 ± 13.765	B
GIC-5% (w/w) TiO_2	10	110.719 ± 12.095	B
Sig.		.003	

* Mean values with different letters indicate significant difference between them (p<0.05)

Table 3: One way ANOVA test for the surface roughness

	Sum of Squares	df*	Mean Square	F	Sig.**
Between Groups	.036	2	.018	48.032	.000
Within Groups	.010	27	.000		
Total	.047	29			

* df= degree of freedom

** P< 0.05 mean significant difference exist

Table 4: Tukey analysis of mean ± standard deviation values of surface roughness in (μm), subset for alpha= 0.05.

Groups	N	Mean ± SD (μm)	Tukey grouping*
GIC-control	10	0.175 ± 0.020	A
GIC-3% (w/w) TiO_2	10	0.138 ± 0.019	B
GIC-5% (w/w) TiO_2	10	0.090 ± 0.017	C
Sig.		.000	

* Mean values with different letters indicate significant difference between them (p<0.05)

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