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AN *IN-VITRO* STUDY OF THE PHYSICO-MECHANICAL PROPERTIES OF A NEW ESTHETIC RESTORATIVE *versus* DENTAL AMALGAM

Estudo in vitro das propriedades mecânicas de uma nova restauração estética versus amálgama dentário

Neveen M. Ayad[1], Salwa A. Elnogoly[1], Osama M. Badie[2]

[1] Lecturer of Dental Materials, Department of Dental Biomaterials, Faculty of Dentistry, Mansoura University, Egypt, e-mail: neveenmokhtar@yahoo.com
[2] Assistant Professor of Production Engineering and Machine Design, Department of Production Engineering, Faculty of Engineering, Mansoura University, Egypt.

Abstract

OBJECTIVES: The aim of this study was to determine the compressive strength (CS), diametral tensile strength (DTS), surface hardness (SH), and surface roughness (SR) of a ceramic-reinforced glass ionomer in comparison to a high-copper dental amalgam. The microstructure was also examined. **MATERIALS AND METHODS**: A ceramic-reinforced glass ionomer (Amalgomer CR), and a spherical admixed high-copper dental amalgam (GS.80) were used in this study. Specimens were fabricated from the tested materials according to the instructions of each manufacturer. The CS, DTS, SH, and SR were measured after storing the specimens for 1 day and 1 week in water at 37 ^{o}C. Independent-samples t-test and paired–samples t-test were used to determine which specimen groups were significantly different for each test. One representative specimen of each material was prepared and examined for microstructure using scanning electron microscopy (SEM). **RESULTS**: At 1 day, ceramic-reinforced glass ionomer exhibited significantly-higher CS and DTS, lower SR. At 1 week, it exhibited significantly-higher CS and lower SR. The results of SH were not significantly different between the tested materials at both storage periods. **CONCLUSION**: The physico-mechanical properties of the tooth-colored ceramic-reinforced glass ionomer were so close and sometimes significantly superior to dental amalgam.

Keywords: Glass ionomer material; Compressive strength; Dental amalgam; Physico-mechanical properties.

Resumo

***OBJETIVOS**: O propósito deste estudo foi determinas a resistência à compressão, resistência à tensão diametral, dureza de superfície e aspereza de superfície de um ionômero de vidro reforçado com cerâmica em comparação com amálgama dentário com alto conteúdo de cobre. A microestrutura foi também examinada. **MATERIAL E MÉTODO**: Um ionômero de vidro reforçado com cerâmica (Amalgomer CR) e um amálgama com limalha esférica com alto conteúdo de cobre (GS.80) foram utilizados neste estudo. Os corpos de prova foram produzidos com os materiais testados, de acordo com instruções dos fabricantes. O CS, DTS, SH e SR foram medidos após estocagem dos corpos de prova por um dia e uma semana em água a 37 ºC. Amostras foram testadas (t-test e t-test emparceiradas), usadas para determinar qual grupo de corpos de prova foram diferentes significativamente para cada teste. Um espécime representativo de cada material foi preparado para avaliação da microestrutura utilizando microscopia eletrônica (SEM). **RESULTADOS**: Após um dia, o ionômero de vidro reforçado por cerâmica exibiu significativamente maiôs CS e DTS e menor SR. Após uma semana, exibiu significativamente maior CS e menor SR. Os resultados do SH não foram significativamente diferentes entre os materiais testados em ambos os períodos de estocagem. **CONCLUSÃO**: As propriedades físico-mecânicas do ionômero de vidro com cor de dente, reforçado com cerâmica, foram semelhantes e algumas vezes superiores ao amálgama dentário.*

***Palavras-chave**: Material ionômero de vidro; Resistência à compressão; Amálgama dentário; Propriedades físico-mecânicas.*

INTRODUCTION

Glass ionomer cements (G1C) possess certain unique properties including release of anticariogenic fluoride into adjacent tooth structures, chemical bonding to enamel and dentine, and a low coefficient of thermal expansion similar to tooth (1). They are, however, susceptible to fracture and exhibit low wear-resistance (2). These deficiencies have limited their use, and made them unsuitable for high-stress areas such as class I and II restorations. Because of their low tensile strength, fracture toughness, and brittleness, a variety of modifiers have been added to conventional glass ionomers, to improve their mechanical properties. In 1977, the addition of amalgam alloy powder to glass ionomer was expected to increase the strength and provide radio-opacity (3). A variation of this proposed material was marketed as Miracle Mix (GC Corporation, Tokyo, Japan) in 1983. Subsequently, ESPE produced Ketac Silver (ESPE, Seefeld, Germany) where silver particles were sintered to the glass to form a cermet (ceramic-metal) cement. While some investigators found no significant difference between the strengths of conventional and metal-reinforced glass ionomers (4, 5), others have found otherwise. (6, 7). Because of the metal additives, metal-reinforced cements are not tooth-colored and color ranges from light to dark gray. Also, the absence of interfacial bonding, which is critical for efficient transfer of stress from the matrix to the reinforcement, may explain why metal-reinforced materials have not proved to be stronger or more durable than their metal-free counterparts (8).

In the late 1980´s, the addition of polymerizable hydrophilic resins to conventional glass ionomer cements resulted, in the development of resin-modified formulas that set by a dual reaction: the acid–base reaction and a free radical polymerization process (9, 10). In general, resin-modified glass ionomer cements were reported to show better mechanical properties than conventional glass ionomers, even though there are individual differences from one brand to another (10-13) Still their polymerization shrinkage and low wear resistance constitutes a major drawback (12, 13).

Recently, a new ceramic-reinforced glass ionomer has been introduced to the dental market. This tooth-colored product is proposed by the manufacturer to combine the high strength of a metallic restorative, and the esthetics and other

advantages of glass ionomers. The objective of this in-vitro study was to evaluate some important physical-mechanical properties of ceramic-reinforced glass ionomer in comparison to high-copper dental amalgam.

MATERIALS AND METHODS

Materials

A ceramic-reinforced glass ionomer restorative, water-settable powder (Amalgomer CR, Advanced Healthcare Ltd; Tonbridge, Kent, UK), and one admixed non-gamma 2 amalgam alloy, capsule-form (GS.80, SDI, Australia) were used in this study.

Specimens' preparation

Tested materials were manipulated according to each manufacturer's instructions. Cylindrical specimens were prepared in split Teflon molds with dimensions of 4mm diameter and 8mm thick for testing compressive strength and surface roughness, 6mm diameter and 3mm thick for testing diametral tensile strength and surface hardness. Amalgam capsules were mixed for 8 s in a high speed capsule mixture HSMI (GC International Corporation, Singapore Branch, Singapore). The mixed materials were injected directly into the molds that were slightly overfilled and compressed using glass plates. The extruded excess material was removed. The specimens were removed from molds after 15 min and varnish coating was carried out for glass ionomer specimens. Specimens were stored in distilled water at 37± 1° C and subjected to testing at 1 day and 1 week.

Strength measurements

Mechanical testing of specimens was conducted in accordance with the British Standards specification for dental GICs BS6039: 1981, (14) using an Instron universal testing machine, Lloyd, type 500, (Lloyd) instrument, England, at a crosshead speed of 1 mm/min for both the compressive strength CS and diametral tensile strength DTS.11 For each test, 5 specimens of each material were tested at 1 day and 5 others at 1 week.

Compressive strength

Specimens were placed with the flat ends between the platens of the testing machine so that load was applied in the long axis of the specimens. The maximum load applied to fracture the specimen was recorded and CS (MPa) was calculated using the formula: $CS = 4P/\pi\ d^2$ where P is the maximum applied load (N) and d is the diameter of the specimen (mm).

Diametral tensile strength

Specimens were placed with the flat ends perpendicular to the platens of the testing machine so that load was applied to the diameter of the specimens. The maximum load applied to fracture the specimen was recorded and DTS (MPa) was calculated using the formula: $DTS = 2P/\pi\ dt$ where P is the maximum applied load (N), d is the diameter of the specimen (mm) and t is thickness of the specimen (mm).

Surface hardness measurement (SH)

Before testing, the specimen surface was wet-ground with 1000-grit silicone carbide paper at room temperature. Microhardness measurements were obtained using a digital Vickers microhardness tester (MXT70, Matsuzawa, Tokyo, Japan). A 25 gf load was applied for 5 s indentation time via the Vickers diamond pyramid. Three readings were taken for each of 3 specimens of each investigated material at 1 day and another 3 at 1 week, and the mean VHN was computed.

Surface roughness measurement (SR)

The average surface roughness (Ra) of three specimens of each tested material was measured using a surface profilometer, SJ.201, Mitutoyo, Tokyo, Japan. The cut-off value for surface roughness was 0.8 mm and the traversing distance of the stylus was 4 mm. The radius of the tracing diamond tip was 5 μm and measuring force and speed were 0.4 gf and 0.5 m/s, respectively. The average roughness value Ra (μm) of each specimen was obtained as the mean of the Ra values measured in three different positions.

Statistical analysis

Data entry and analyses were performed using SPSS statistical package version 10 (SPSS, Inc., Chicago, IL, USA). The quantitative data were presented as means and standard deviations. Independent-samples t-test was conducted to compare the means of continuous variable for two different groups of individuals. Paired-samples t-test was conducted to evaluate the impact of time on the mean of continuous variable (compressive strength, diametral tensile strength, surface hardness, and surface roughness) of each group of individuals. The tests were considered significant when $p<0.05$ and highly significant when $p<0.001$.

Scanning electron microscopic (SEM) examination

After surface roughness testing was carried-out, one representative specimen of each tested material was prepared for scanning electron microscopy, ISM-840A, Jeol, Tokyo, Japan. Specimens were sputter-coated with gold to a thickness of approximately 50 A^{o} in a vacuum evaporator, MED 010, Balzer Union, Balzers, Liechtenstein. The specimens were evaluated with a magnification of X 3500 at an accelerating voltage of 20 kV.

RESULTS

The mean values and standard deviations of the CS, DTS, SH, and SR of Amalgomer CR and GS.80 after 1 day and 1 week water storage are shown in Table 1.

TABLE 1 - Means, standard deviations, t-value and p-value of CS, DTS, SH, and SR of the tested materials after each storage period

Storage time	Test	Amalgomer CR	GS.80	t-value	p-value
1 day	CS (MPa)	340.7(2.303)	313.1(1.334)	22.963	0.000
1 week	CS (MPa)	382.5(1.857)	374.0(0.893)	9.160	0.000
1 day	DTS (MPa)	27.7(0.03)	23.7(0.368)	24.268	0.000
1 week	DTS (MPa)	31.4(1.45)	33.9(3.03)	-1.691	0.129
1 day	SH (VHN)	35.1(1.16)	32.4(2.02)	2.057	0.109
1 week	SH (VHN)	39.4(1.5)	40.2(4.5)	-.0292	0.785
1 day	SR (μm)	1.12(0.25)	2.56(0.49)	-4.480	0.011
1 week	SR (μm)	1.23(0.05)	2.91(0.22)	-12.860	0.000

Standard deviations are given in parenthesis.

TABLE 2 - t-values & p-values of paired samples t-test showing the interaction between tested materials and storage time for different tests

Material tested	CS done at 1 day and 1 week		DTS done at 1 day and 1 week		SH done at 1 day and 1 week		SR done at 1 day and 1 week	
Amalgomer CR	t-value	p-value	t-value	p-value	t-value	p-value	t-value	p-value
	-28.453	0.000	-5.710	0.005	-3.781	0.063	-0.770	0.522
GS.80	t-value	p-value	t-value	p-value	t-value	p-value	t-value	p-value
	-80.102	0.000	-7.800	0.001	-3.793	0.063	-1.233	0.343

From Table 1, at 1 day, highly significant differences ($p<0.001$) in compressive strength, and diametral tensile strength were observed between the two tested restorative materials. A significant difference ($p<0.05$) in surface roughness was also observed. No significant difference ($p>0.05$) was detected in surface hardness. At 1 week, highly significant differences in compressive strength, and surface roughness were observed between the two tested restorative materials. No significant difference was detected in surface hardness, or diametral tensile strength. The paired samples t-test (Table 2) revealed highly significant interaction between materials and storage time for compressive strength, a significant interaction for diametral tensile strength, but no significant interaction for either surface hardness or surface roughness for either Amalgomer CR or GS.80. Figures 1 and 2 are representative for the surface roughness curves obtained using the surface profilometer for both tested materials. The SEM examinations of the tested materials are displayed in Figures 3 and 4.

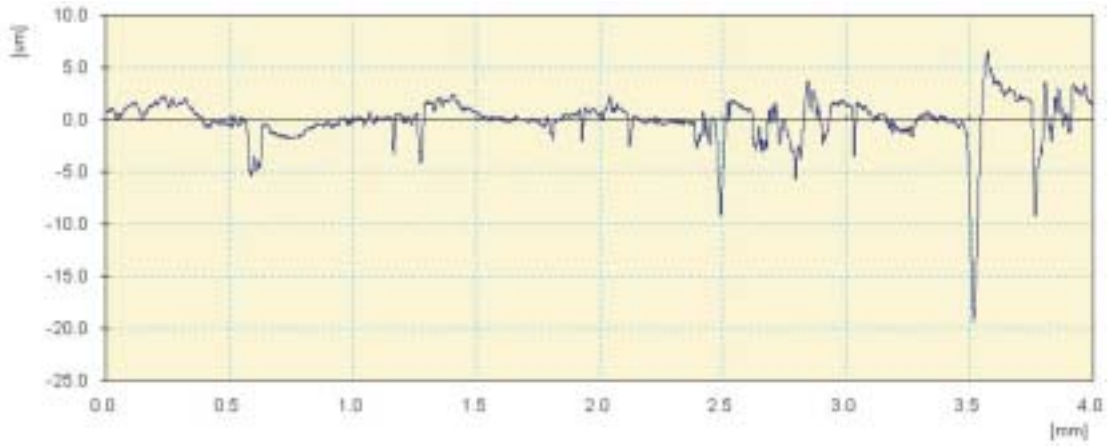

FIGURE 1 - Average roughness curve for Amalgomer CR

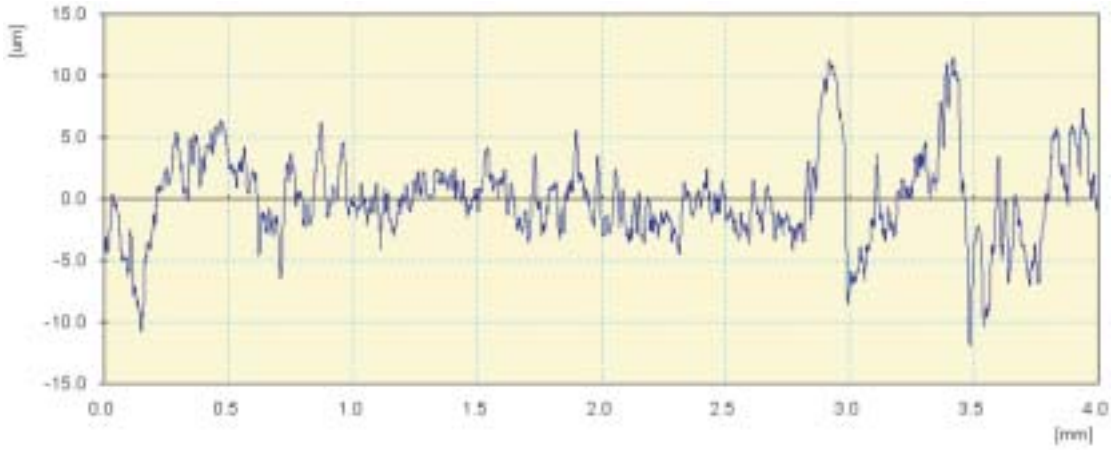

FIGURE 2 - Average roughness curve for GS.80

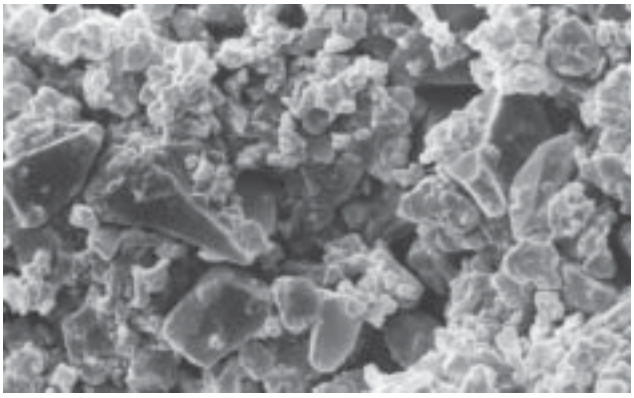

FIGURE 3 - SEM Photographs (x 3500) of the ceramic-reinforced glass ionomer Amalgomer

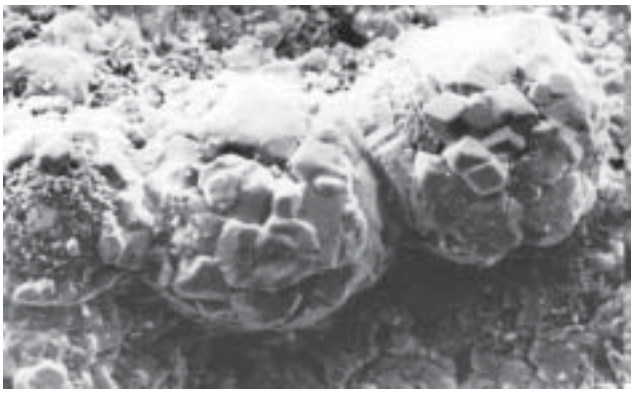

FIGURE 4 - SEM Photographs (x 3500) of the high-copper dental amalgam GS.80

DISCUSSION

The resistance to fracture within a restorative material is specified by a fracture stress, which is often referred to as the strength of the material. Many brittle dental materials such as cements and amalgam have a tensile strength that is markedly lower than the compressive strength. These materials fail by crack propagation that is favored by tensile rather than compressive loading. Some authors (15) consider the compressive strength test to have no fundamental meaning for materials such as GIC that would fracture mainly by tensile or shear failure, still the indirect relation of compressive strength to both tensile and shear modes of failure makes it a useful testing parameter.

There has been large variability in tensile data on brittle materials. Although special grips have been used to permit axial tensile loading with a minimum of localized stress concentrations, obtaining uniform results is still difficult, and such testing is relatively slow and time consuming. An alternative method of testing brittle materials, in which the ultimate tensile strength of a brittle material is determined through compressive testing has become popular because of its relative simplicity and reproducibility of results. This method is described as the diametral compression test for tension. In this test method, a disk of the brittle material is compressed diametrically in a mechanical testing machine until fracture occurs.

In this study, mechanical testing was conducted in compliance with BS6039: 1981 at 1 day and at 1 week. Amalgomer CR showed higher compressive and diametral tensile strength values at 1 day than those of GS.80 and the difference was highly significant at $p < 0.001$. At 1 week, Amalgomer CR had higher compressive strength value than GS.80 and the difference was highly significant, but lower diametral tensile strength value and the difference was not significant, $p > 0.05$. For both tested materials, compressive strength values were much higher than diametral tensile strength values. Compressive strengths were about 13 times greater than diametral tensile strengths. This finding is in agreement with that of Suzuki et al. (16). For both tested materials, at 1 week, the increase in compressive strength values was highly significant, and the increase in diametral tensile strength values was statistically significant.

Hardness can be defined as the resistance of a material to indentation or penetration (17). For Vickers hardness measurement, the hardness number increases as surface hardness increases. Change in hardness may reflect the state of cure of a material and the continuation of a setting reaction (18, 19). Amalgomer CR showed higher mean VHN values at 1 day than those of GS.80 and the difference was not significant, $p > 0.05$. At 1 week, Amalgomer CR showed lower mean VHN values than GS.80 and the difference was not significant, $p > 0.05$. Both tested restorative materials showed higher mean VHN values at 1 week than at 1 day, and the difference was not statistically significant. Results may reflect the hardening phase of the setting reaction in case of glass ionomer due to continued formation of aluminum salts bridges (20) and due to the increased number of γ_1 crystals during the amalgamation process of amalgam.

Surface roughness can influence the behavior of the restorative material very greatly. A surface profilometer can be used to obtain roughness measurements in Dentistry (21, 22). The average

roughness (Ra) is defined as the arithmetic average of the absolute values of the measured profile height of surface irregularities in micrometer measured from a mean line within a preset length of the specimen. In this study, Amalgomer CR showed lower surface roughness values than GS.80, where the difference was significant at 1 day, $p<0.05$, and it was highly significant at 1 week, $p<0.000$. For both tested materials, no significant interaction was detected between surface roughness and storage time.

CONCLUSION

Within the limitations of this study, it is evident that ceramic-reinforced glass ionomer restorative material has physico-mechanical properties that are so close and even superior to dental amalgam. Further research is being performed to determine wear resistance and clinical performance of ceramic-reinforced glass ionomer restorative.

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