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An investigation into the physical characteristics of dental fillings at the nanoscale

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Abstract

Background: Dental fillings play a crucial role in restorative dentistry, providing a solution for repairing damaged or decayed teeth. These fillings are subjected to various mechanical, chemical, and biological challenges within the oral environment, which can impact their longevity and performance. Understanding the physical characteristics of dental fillings at the nanoscale is essential for improving their design, durability, and biocompatibility.

Experimental procedures: The experimental procedures commenced with a meticulous evaluation of the mechanical characteristics, delving into parameters like hardness and compressive strength. Employing cutting-edge atomic force microscopy (AFM), we scrutinized various concentrations of incorporated nanomaterials, spanning from 0% to 7.5% by weight. This meticulous investigation sought to uncover how these nano-additives influenced the mechanical prowess of the composite**.**

Outcome: Among the various equipment's and tools including AFM, the visual representations of the PMMA provided highly detailed account of the surface topography after incorporating nanomaterials and before it. Roughness, RMS, and average particle size are some of the surface related changes that we observed on the AFM images. This change was attained through effective incorporation of nano-oxides and expansion of the parts they take up.

Conclusion: the designing of nano-composites (PMMA-ZnO-MgO) for dental restoration applications has significantly led to the discovery of results-yielding samples, and the comprehensive analysis also proffers evidence on what has been obtained. Nanomaterials, when considered in the context of the pure polymer matrix, have a remarkable impact that contributes to the overall changes in as roughness, roughness rate, average root mean square (RMS) value, and average grain size. This enhancement reflects the contiguity between the concentration of pollutants and the nanomaterials in this case being the determinants of the characteristic shapes of the composites.

Keywords: PMMA, ZnO, MgO, mechanical properties, structural properties, dental fillings

Introduction

Dental caries, commonly known as tooth decay, stands as one of the most prevalent dental afflictions affecting individuals worldwide. Plaque, a microbial biofilm that accumulates on tooth surfaces, serves as the primary catalyst for dental decay. Bacteria residing within plaque metabolize sugars and remnants of starchy foods, producing acids that erode the enamel and dentin of teeth by leaching essential minerals such as calcium [1]. Caries typically initiates on the outermost layer of the tooth, the enamel, particularly in fissures, pits, and interproximal spaces, and progressively advances to affect the underlying dentin and, in severe cases, the tooth pulp. While fluoridation of water has proven effective in reducing the incidence of tooth decay, regular oral hygiene practices such as brushing and flossing remain paramount [2]. When decay does occur, the removal of diseased dental tissue followed by restoration with filling materials becomes necessary.

In recent times, considerable attention has been directed towards a class of materials known as polymeric nanocomposites. These innovative materials consist of organic polymers integrated with inorganic nanoparticles, holding immense promise across various industries including microelectronics, healthcare, transportation, and more [3].

The multifaceted applications of nanocomposites are attributed to their ability to modulate the optical, electrical, thermal, and mechanical properties of constituent nanomaterials, thereby offering superior performance characteristics [4].

Nano-medicine, a novel dimension at nanotechnology-medicine crossroads, purposes of diagnosing, treating, monitoring, and managing diseases have gained a lot of attention [5]. Nanotechnology is a keystone of nano-medicine which provides us a wide range of implementations involved in the fabrication of nanomaterials and biological devices as well as nano-electronic biosensors [6]. The nanomaterials brought in an entirely new era in diagnostics, therapeutics, physical therapy, and drug delivery, all of which together lead to significant changes [7].

While the role of nano-medicine in drug delivery system and *in vivo* imaging illustrate the new dawn of precision medicine, nano-medicine appears to have a great potential [8, 9]. Nanotechnology as it advances and immerses into our lives will certainly create a vast arsenal of research instruments and a wide range of clinically significant equipment, which thereby will change the landscape of health care sector in the coming times.

Materials and Methods

Method of preparation: The present research will be centered on poly-methyl-methacrylate (PMMA), which would be the primary polymer being studied. Usually seen in powdered kind, PMMA (Polymethylmethacrylate) features a high level of purity, because it can be acquired from local markets at a purity level of 99.98%. The zinc oxide (ZnO) particles having diameter ranging 20-30nm are prepared from the EPRUI well known suppliers whose purity is up to 99.9%. Likewise, magnesium oxide (MgO), depicting an equally critical filler, was manufactured by EPRUI, showing a particle diameter of 20-30 nanometers.

The main part of our manufacturing process is the careful immersing of the proper fillers into the base polymer PMMA which is then dissolved in Chloroform or Chloromethane. Chloroform, moreover known as chloroform, is a compound that can be employed for various organic purposes. This compound is regarded as a colorless liquid, which evaporates quickly. Moreover it demonstrates high solubility for many compounds and its density with 1.49 g/cm3 is high enough. The dissolution process involves mixing the polymer with 30 cc of chloroform to be sure that the mix is agitated continuously for 30 minutes to achieve uniform blend. Next, the initiators, i.e. ZnO and MgO fillers, are carefully put into the solution while consistently stirring the mixture with a mechanical stirrer for about ten minutes at room temperature to achieve a uniform dispersion throughout the mixture.

In the present study, the volume percentages of reinforcements are 0, 2.5, 5, and 7.5 which, being chosen as the level of analysis make it possible to study the correlation between the composite properties and the fillers. To make fabrication of the nanocomposites (PMMA-ZnO, MgO) I use casting which is the method of suing a 10 cm in diameter dish with a petri dish as a substrate. This thickness range of samples has been measured from 0.011 to 0.0105 m, using a digital micrometer, thus bringing out the precision aspect.

In order to study the description of the outside part of the sample and the shape of the fabricated samples, the state-of-the-art Atomic Force Microscope (AFM) is utilized. The AFM comprises a superiority in terms of subsurface analysis thanks to its capability to scrutinize a range of surface size that can reach from 100 nm to less than 1 nm [1]. (Table 1) illustrates the weight percentages of zinc oxide that were added to the composite matrix.

Then, the castings undergo a series of tests through which samples are selected and further studied. The analysis process usually includes selecting and experimenting with samples.

Table 1: Displays the weight percentages of nanocomposites consisting of PMMA, ZnO, and MgO.

wt.%	PMMA g	ZnO g	MgO g	Weight of Sample
0	1	0	0	1 gm
3.4	0.864	0.0136	0.0134	
7	0.84	0.036	0.034	
9.7	0.834	0.0486	0.0386	

In this experiment, the manufacturing and analysis of six different dental composite samples employed two distinct moulds which could be of stainless steel type [11]. This is the first mould design with a cylindrical hollow body specifying the external diameter as 6mm and the body thickness of 10 mm. Sampling of 2 inches can be achieved by a 6mm-thick iron rod with an 8mm diameter inserted into the cavity. This method ensures a uniform sample thickness and, by the way, it is specifically used in the analysis of the hardness of the samples.

Also, the second mould model which is a similar equivalent to the first one model being made a hollow cylindrical size of 6 millimeters outer diameter and 3 millimeters inner diameter. This particular mold type is useful for creation of samples used for compression strength inspection. One of the main mechanical properties, compressive strength, related to the material ability to resist the pressure before the deformation or failure, is among the most critical ones. It is a mix of different material that is made up of various ingredients, of which the particles of the filler are the most important. As for the filler size, diameter and composition, they provide drastic effect on the compressive strength of the cement [12].

The strength test that is performed under compressive force is effective in the casting of dental impressions and is a crucial element of dental material selection since these materials need to have mechanical properties similar to natural teeth to endure the pressures of the chewing process. Composites, amalgams, cements and similar materials, being compressed exhibit much better survival rates in respecting as compared to tensile resistance. To this end the composite resin used in the study is forecasted to have 450-500 Newton (N) compressive strength.

A compressive stress test which evaluates from the point of view of dental composite behavior under compressive chewing pressures emerges as the best approach for this examination followed by the results which are obtained. The importance of the resistance in clinical applications becomes obvious from this fact; therefore, it is required to conduct compressive strength tests for these materials as a part of their safety investigation.

As per ISO 9917 [13], the compressive strength test for dental overlays requires cylindrical models with a length to diameter ratio of 2: Firstly, sports play a significant role in community development. This specific ratio stands for the balance between bending forces that the model should not endure. The compressive strength is one of the most important factors to be considered and can be determined with the help of this equation. "You can refer to a source or cite it" the user's text is a period.

The equation (1) stands for the compensation of stress (σ) with the pressure (P) and cross-sectional area (A).

Where: - σ represents the compressive strength, measured in

N/mm^2. - P represents the applied load, measured in N. A: Area for loading in square millimeters (mm^2)

Findings and Analysis

Fig. (1) demonstrates the external surface morphology of the nanopolymer filling samples with and without specified concentrations of the guests through visual graphics before and after incorporation, as shown in Figs. (2) (3) and (4). It can be therefore concluded that this comparison can help to understand the effect of filler proportions on the surface properties.

The table (1) features zinc oxide percentages of the composite mixtures as implemented in the corresponding samples and shows the systematic evolution in filler amount (1).

After the casting procedure, the samples produced in fabrication are investigated by atomic force microscopy (AFM) method which is a qualitative technique that generates high-resolution images in three dimension. AFM, employing a laser beam refractor, allows atomic level study of the surface as it is regarded with a very high precision. With the help of AFM, we can trace the changing layout of the topography and also record it in a manner that helps us see molecular arrangements and structural features with exceptional clarity.

During such study, AFM discloses higher amounts of molecules having such clusters according to some special regions, consequently the molecules form groups or clusters on the surface. These granules are adding up to the enhancement of the macro-scopic roughness, a big deal that helps in the strength-endurance, bonding and stability of dental fillings. On the one hand, however, the size of the film should be kept under the 200 nm limit, as this is the primary factor that determines the formation of dental plaque and makes it more difficult to remove by brushing or flossing (See Table 2 [16].

The increase in roughness height corresponds with large RMS values (root-mean-squared) and big average size of grains produced by the effect of pollutants at increased amounts. The incorporation of nano-oxides will create the agglomeration, which will in turn lead to the betterment of the dental solidification process and improvement of the dental intensity or packing durability.

Another factor investigated by our team revealed uniform distribution of molecules in the matrix which led to better material properties, strength, and toughness. The distribution of the powdered samples by this mechanism not only facilitates the faster stacking but it also improves the crystal structure through increased manifestation of nano-oxides, supporting the researcher's claims in reference [17].

AFM study gave a good idea for nano-polymer fillings that fillers play vital roles in the mechanical and structural properties, and these findings may be a good point for further research and development in this field.

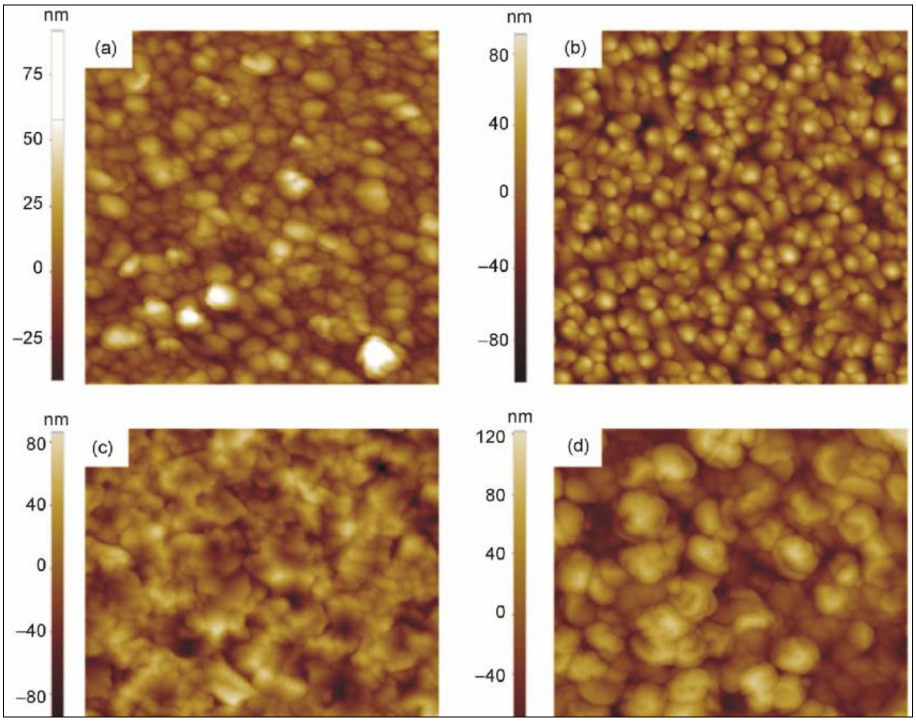

Fig 1: Displays the Atomic Force Microscopy (AFM) three-dimensional picture of the filler material before and after the addition. (a) Pure PMMA, (b) PMMA with 2.5 wt.% ZnO and MgO, (c) PMMA with 5 wt.% ZnO and MgO, (d) PMMA with 7.5 wt.% ZnO and MgO

The most important feature of the fillings are the compressive strength (σ) of them. The compressive strength test is an important part of laboratory tests, as it provides a beneficial feel-good factor for dentists to pick a suitable filling material that will stand up to the varying biting pressures inside the mouth. As to this fact, dental fillings must be made from materials with a high level of compressive strength to resist external forces and pressures.

According to quality standards which abide ISO 9917, all samples used to evaluate their mechanical strength by mimicking mastication [18]. The experimental setup adhered to specified parameters, including a length-to-diameter ratio of 2: By using a 0.5 cm/m width of stroke and paying close attention to ensure that the results meet the established guidelines [19], I guarantee consistency and reliability as regards the results.

The study primarily focused on assessing the compressive strength of fillings which are functionalized with nanocomposites that contain PMMA-ZnO-MgO. The tests proved to deliver eye-opening benefits in compressive strength with the highest 150 Mpa obtained at the concentration of 7.5% g (g = graphene concentrate). Followed by encouraging strength measures of 146 Mpa (5% g) and 138 Mpa (2.5% g), these evaluations pinpoint out the great mechanical capacity of the nanomaterial add.

Among the unique properties of magnesium oxide is its ability to increase the fiber matrix synergy, which results in enhanced strength and toughness due to its hexagonal crystalline structure. This particular structural formation enables the bond-building and bond-breaking with other compounds, which explains why the material's architectural strength is a critical factor. Due to the powerful coupling capacity of the chemical bonds, particularly the covalent bonds and coordination covalent bonds, the mechanical reinforcing of the polymer is improved to an optimal level, thus giving the compound structure with a higher density of fillers.

The data in Table 3 provide evidence that different factors come into the picture for making up the compressive strength, which not only include the composite material composition but also the filler type and the filling dimensions. Nanomaterials and nanopolymers integration, which leads to materials upgrading, is a distinct performance highlight of such nanocomposites, which offers a glimpse of the transformation level of nanocomposites in oral applications.

In brief, the findings highlighted the critical effect of the nano material additive on the mechanical strength of dental fillings. This means that future of restorative materials development is based on the nanotechnology development that will be able to withstand everyday oral function.

Table 2: Presents the characteristics of compressive strength (σ) for nanocomposites consisting of PMMA, ZnO, and MgO.

Material	σ (MPa)at 2.5% g	σ (MPa)at 5% g	σ (MPa)at 7.5% g	Σ (MPa) of PMMA
(PMMA- ZnO-MgO)	139	156	160	140

Table (3) enlists the values, in the units of MPa, that the two types of fillings are found to have in the study. The discovered rise of hardness can be connected with the special features which are conferred by the hexagonal form and solid bonding between the composite components. The more additives are mixed, the harder the surface and the overall hardness of the filling material will be significantly improved.

The fillings which are hexagonal in shape are known to posses tough bonding with other parts of the teeth that enhance their durability and strength. The unique architectural design makes it possible for the material to act as an agent of strengthening intermolecular bonds and therefore the resultant materials are stronger. Besides that, the lack of free space between molecules results in a higher level of packing density. This additional compliance contributes to the material's toughness and long-term stability.

It is noticeable that all of researched nanocomposites were in the range of hardness that exceeded 50 MPa, and according to the ISO standards, their value meet or even exceed the standards that have been mentioned above [22]. This confirms the fact that fabricated fillings contribute to the high standards and performance dependability for dental materials.

In addition to the differences in physico-chemical features, which are displayed by the fillers as a result of the existence of nanoparticles, they also have unique characteristics despite the fact that they have equal dimensions. They are not solely controlled by the size of the nanoparticles but by their intrinsic characteristics that belong to each material type. The factors like surface chemistry, morphology and crystalline structure of the constituents play significant role in improving overall performance of the fillers in various respects and they prove to be crucial in understanding the complex nature of nanocomposite formulations.

However, these fragments not only are made by the human but also the damage they do. The application of fillers onto materials creates an extremely scratch resistant surface of the material in this context due to the greater that provides [23, 24].

Table 3: Presents the hardness characteristics for the composite material consisting of polymethyl methacrylate (PMMA), zinc oxide (ZnO), and magnesium oxide (MgO)

Material	Hardness (MPa) at 2.5% g	Hardness (MPa) at 5% g	Hardness (MPa) at 7.5% g	Hardness (MPa)of PMMA
(PMMA- ZnO -MgO)	84.3	86.6	90.7	**82**

Conflict of interests

There are non-conflicts of interest.

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