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Comparison of the effect of modified and unmodified silicon nanoparticles on moisture absorption and mechanical properties of dental samples made of polymethyl methacrylate

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Abstract

In this study, the effect of adding modified and unmodified silicon nanoparticles with different weight percentages (0,2, 5, 7, and 10 wt%) on the amount of moisture absorption in environments with different PH (5, 6, 7, 8, 9) Also, the fracture toughness of polymethyl methacrylate samples have been discussed. The fracture toughness was tested by the three-point bending method according to the ASTM D5045 standard and the amount of moisture absorption according to the absorption test according to the ASTM D570 standard. Production samples by compression molding method, were evaluated in terms of structure and properties using SEM method. SEM images show that up to 7% by weight of the filler, the dispersion of silicon particles in the modified silica state is significantly better than in the unmodified silica, but at 10% by weight of the filler, the dispersion of the particles in the two modified states and unmodified is similar and not uniform. Experimental results show that increasing silicon improves the fracture toughness of parts made with unmodified silicon up to 2% by weight of filler, but for parts made with modified silicon up to 7% by weight of fracture toughness but this improvement is optimal when 5% by weight of silicon is used. Also, increasing silicon has increased moisture absorption in both groups of samples produced with modified and unmodified silica, so that as the percentage of filler increases, the rate of moisture absorption increases. On the other hand, as the acidity or alkalinity of the liquid progresses to neutral, the reaction between the base polymer molecules and the test liquid decreases, increasing moisture absorption. No significant difference was observed between moisture absorption in the modified and unmodified silicon.

Keywords: polymethyl methacrylate, modified silica nanoparticles, unmodified silica nanoparticles, fracture toughness, moisture absorptiond
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1 Introduction

Polymethyl methacrylate is used in medical and dental applications due to its high biocompatibility [21]. Although PMMA has lower wear resistance, hardness, and fracture toughness compared to amalgam, due to its low cost, beauty and desirable color, excellent thermal stability, and high flexibility, it has rapidly replaced amalgam in dental

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PMMA

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applications [31, 1, 4]. Any restorative material or dental prosthesis must have sufficient mechanical ability to perform properly against pressures in the oral cavity for a long time [17, 10]. Fracture of teeth made of PMMA is prevalent and is considered a serious problem for their use as dental prostheses [3]. Research shows that between 63 and 68% of artificial dental prostheses break after a few years after being made, due to an accidental fall on a hard surface outside the mouth [38]. Most fractures of artificial teeth are caused by weakness in the base polymer. During their performance, dental composites are subjected to various stresses, including compressive, tensile, and shear stress [27]. Therefore, it is very important to study the mechanical properties of these materials to use them in clinical fields [5]. To improve the properties of PMMA, researchers have evaluated the effect of various factors such as fillers, matrices, and also the interface between the matrix and the filler, but the results show that with the change in the matrix of the composites, their properties have not changed significantly. Therefore, studies have focused on fillers [44]. The properties of composites reinforced with nanofillers depend on the size, shape, type, concentration, and dispersion of nanomaterials in the polymer field [19, 34].

In recent years, many nanoparticles such as ZrO_2, SiO_2, TiO_2, and also diamond nanoparticles have been used to increase the physical and mechanical properties of PMMA [2, 13, 14, 41].

Silicon dioxide nanoparticles, which are also known as silica nanoparticles or nano-silica, are one of the most common mineral fillers [9, 15, 25] due to molecular stability, low toxicity, and the ability to bond with a wide range of molecules and polymers, as well as antimicrobial properties [6, 18], they are the basis of biomedical research.

Silica nanocomposites have less weight compared to normal composites, and this factor has made them a suitable substitute for polymers in various applications [35, 42]. Silica nanoparticles are used to improve the mechanical properties, adhesion, durability, and wear resistance of polymers. Nano silica generally has an amorphous and hollow (mesoporous) structure [12, 24]. In some cases, the crystalline structure of nano-silica can be obtained, which is usually impossible to detect from X-ray tests. The best shape for silica nanoparticles for suspension is spherical [30]. This spherical form is accessible by synthesis in an ammonia medium. Most of the nano-silica particles are used for industrial purposes with one size (suspension) and two hydrophobic sizes (separation of oil and water). Due to the presence of a hydroxyl group on the surface of nano-silica particles, the ability of these particles to agglomerate when combined with polymer composites is high, and this reason makes it difficult to prepare PMMA composite reinforced with nano-silica [26].

Currently, to overcome the existing problems, many studies have been conducted on the modification of nanosilica surfaces by chemical interaction because it leads to a much stronger interaction between modifiers and silica nanoparticles. Chemical methods include modification with modifying agents or grafting polymers. Silane agents, the most famous of which are gamma methacryloxy propyl trimethoxy silane, which has the ability of hydrolysis and can reduce the hydroxyl groups on the surface of silicon nanoparticles [47], as a result, it causes a better bond between the filler and the base polymer [37]. This causes the accumulation of silica nanoparticles to decrease when combined with the base polymer.

Many researchers have studied the mechanical behavior of PMMA and SiO_2 multilayer composites. Zhen et al. [45], and Balos et al. [7] found that by increasing silica nanoparticles from 0 to 5%, the tensile strength and elongation at the break of the composites improved, and the flexural strength and elastic modulus increased significantly. Fatalla et al. [16] observed a slight increase in impact strength, transverse strength, and hardness with a negligible amount of 5% by weight of nano silica. Siot et al. [40] believe that although silica nanoparticles increase the static modulus and yield strength of composites, the final properties of the composite are strongly affected by the dispersion characteristics of nanoparticles, and the better performance of silica filler is related to its regular dispersion. Mussatto et al. [32] evaluated the effect of mixing modified and unmodified silica nanoparticles and concluded that by adding silica nanoparticles, the bending strength of the composite in both modified and unmodified states decreased between 20 and 27%, that this reduction was not dependent on the amount of filler and the method of combining nanoparticles, also the surface modification of nano-silica did not cause any major improvement in the mechanical behavior of nano-resins, but it seems to improve the dispersion because the surface roughness is shown to be smaller.

Salman et al [39] observed very significant improvements in impact strength, transverse strength, and hardness by adding nano-silica to PMMA at 3%, 5%, and 7% by weight. They have concluded that the addition of nanoparticles in the optimal state can bring better physical and mechanical properties. Topouzi et al. [43] observed a significant increase in fracture toughness by adding modified and unmodified silica nanoparticles to PMMA, but they concluded that increasing the filler concentration decreases the fracture toughness and of course, there is no significant difference between the fillers. They did not report any significant difference between modified and unmodified fillers. Kundie et al. [29] studied the effects of particles on the micro and nanoscale on the mechanical properties of dental composites, they concluded that the effects of nanoparticles strongly depend on factors such as the type and mechanical properties of mineral nanofillers, the uniform dispersion of nanofillers in the polymer matrix. It depends on the volume fraction of filler particles and the type of silane used.

In this research, we investigated the fracture toughness of dental samples made of PMMA reinforced with nano silica, with different weight percentages, using the three-point bending method. The three-point bending test more accurately simulates the stress applied to the composite during chewing [13]. Although many studies have been conducted in the field of particulate composites and their physical and mechanical properties, in these studies, some factors such as the percentage of filler particles, surface modification of nano-silica, and also the environment to which the material is exposed have received less attention. Especially in the case of particulate composites used in dentistry (dental composites), there is not much information about the relationship between properties and structure, and the acidic or alkaline environments that the composite is exposed to for use as artificial teeth have not been studied. Based on studies, absorbed water reduces mechanical properties such as hardness, transverse strength, and fatigue limit due to its lubricating effect [46]. Also, water absorption causes volume expansion of the dental sample and changes the chewing surface of the posterior teeth [36]. Dimensional change exposes dental samples to internal stresses and then causes cracks and failures in artificial teeth [33]. Therefore, it is important to study the effect of the environment to which these samples are exposed. Karabla et al. [22] observed that the amount of absorbed water increases with the decrease in the size of filler particles.

In this research, by simulating the environment in which the dental samples are placed, we try to have a better understanding of their behavior. For this purpose, we placed the production samples in the PH range of 5 to 9 (the normal PH range of the human mouth), the absorption rate We have compared the humidity in the samples.

2 Experiments

2.1 Materials

In this experimental and laboratory study, metamethyl acrylate polymer with the brand name PMMA was used as a polymer base material. This material is a product of Taiwan Chemical Company with a specific weight of 1.19 gr/cm3. Silica nanoparticles made by Acrosun company in Spain with a size of 20 nm and a purity of 99.5% were used as reinforcing material. To reduce viscosity, Tegdema thinning resin manufactured by Evonic, Germany has been used. The samples were molded using a two-piece aluminum mold with dimensions of $6 \times 4 \times 50$mm. Also, to prevent the samples from sticking inside the mold, acrylic separating liquid made by a Major Italian company was used. Also, to modify the surface of silica nanoparticles, acrylate silane modifier, gamma methacryloxypropyltrimethoxysilane (γ-MPS), which is the most widely used silane coupling agent in dental composites [11, 23, 28], was obtained from Sigm Aldrich, Germany.

2.2 Sample production

In this experiment, we have used two sample groups. The first group is the samples that were produced using modified silicon and the second group is the samples produced with unmodified silicon. In the first group, the surface of silica nanoparticles was modified by using an acrylate silane agent, γ-MPS, and by the hydrolysis-condensation method. For this purpose, a solution of water and alcohol with a weight ratio of 70,30 was used to hydrolyze γ-MPS for 30 minutes. The PH is adjusted by acetic acid around 3-4. Then nanoparticles are added to this solution and kept at room temperature for one week. Nanoparticles are washed with alcohol and then in ambient air, the remaining alcohol is evaporated and the nanoparticles are dried.

To produce each of the samples in each group, first, silica nanoparticles (modified and unmodified) with specific weight percentages (2, 5, 7, and 10%) are mixed with monomer methyl methacrylate powder in a mixer. Grinding is done for 12 minutes with a frequency of 20 Hz and a speed of 100 rpm. To produce nanocomposite samples, the mixture of methyl methacrylate powder and milled nanoparticles was mixed with diluent liquid (Tegdema) according to the manufacturer's instructions, which is done mechanically at room temperature and using a small stirrer.

To prevent the produced dough from sticking to the mold, the mold must be prepared. For this purpose, the surface of the mold is covered with a layer of acrylic separating liquid. After the surface of the mold is dry (this work takes about 20 minutes), Pour the pasty liquid into each part of the mold and then tighten the two parts of the mold together. In the next step, to cook the dough inside the mold, we keep the mold immersed in hot water whose temperature is kept constant at 80 degrees Celsius for 50 minutes, then remove the mold and let it cool to room temperature then we take the sample out of the mold. After baking, the samples were polished with the help of sandpaper first with 600 grit and then with 1000 grit.

It should be noted that 10 samples were produced for each weight percentage of the filler in each group and finally 5 healthier samples with the least defects such as fewer bubbles and smoother surfaces were selected based on theoretical observation. Also, 10 other samples without the percentage of silica stabilizer were produced to compare with the reinforced samples, among which we selected 5 better samples.

Table 1: Nomenclature of the samples based on the percentage of nano-silica

$SiO_2\%$	0	2	5	7	10
Examples of the first group (Modified silicon)	A_1	B_1	C_1	D_1	E_1
Examples of the second group (Unmodified silicon)	A_2	B_2	C_2	D_2	E_2

2.3 SEM test

SEM analysis or scanning electron microscope is a member of the family of electron microscopes, which is used to image the sample and determine its surface characteristics and morphology. In fact, in this method, the image is recorded by electrons, whose magnification power is much higher than that of optical microscopes, and they can take images up to several hundred thousand times. The samples used for imaging in SEM analysis must be electrically conductive. Due to the non-conductivity of the production samples, first, the samples are covered with a layer of gold using a sputtering machine. SEM takes images of different surfaces of the sample transversely to evaluate the gradient of chemical composition on the surface of the samples at a distance as small as 1 micrometer, it allows us to obtain a better analysis of the type and distribution of filler particles on the surface of the PMMA matrix for both groups.

2.4 Moisture absorption test

The moisture absorption test is performed under the ASTM D570 standard. Considering that the PH range of the mouth of a healthy and adult human is between 5 and 9, for this purpose, we performed moisture absorption tests in this range. To increase the contact surface of the samples with the liquid and also the lack of effect of the environment on the pH of the tested liquid, we used closed containers in such a way that each sample was placed in a container and we identified the samples by numbering the containers. The suggested time for the moisture absorption test is 24 hours. The amount of moisture absorption is determined by measuring the weight of the samples before and after placing them in the liquid bath. It is worth mentioning that during the liquid bath tests at a temperature of 20 ± 2 degrees Celsius in temperature equilibrium with the environment

is located and a digital scale with an accuracy of 0.001 grams is used to weigh the samples. If M_1 is the primary mass of the sample and M_2 is the secondary mass of the sample, then the amount of moisture absorption is determined using relation (2.1).

$$\frac{\Delta w}{W} = \frac{M_2 - M_1}{M1} \tag{2.1}$$

2.5 Fracture toughness test

The fracture toughness test of nanocomposites was performed according to the ASTM D5045 standard and by the three-point bending method. In this test, a general test machine with a speed of 1 mm/min was used. The method of loading the composite parts made to determine the fracture toughness is shown schematically, where a rectangular part with an edge crack of length a is subjected to a three-point bending load with a support distance of S.

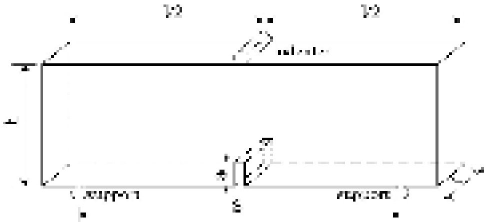


Figure 1: Schematic of the tested sample

Before performing the fracture toughness test to create initial cracks in the samples, the rectangular pieces made were cut using a thin saw blade with a thickness of 0.25 mm. The tips of the notches created by the thin blade are sharpened by pressing a razor. In this way, the grooves created in the samples can be assumed with acceptable accuracy as a sharp crack to perform the fracture toughness test. The length of the final edge crack created in the middle of each sample is equal to 3 mm, as a result of which the dimensionless crack length ratio h/w is a constant value of 0.5 in all the experiments of this research. Before the test, the samples were kept for 24 hours in the standard conditions of the laboratory environment (temperature 23±2 degrees Celsius and humidity 50±5%), then, the cracked samples were placed inside the supports of the three-point bending fixture (with a support distance of S=40mm) in the testing machine and were monotonically loaded at a constant rate of 1 mm/min. Loading continues until the moment of complete failure of parts and crack growth from the initial crack tip, and finally, the load-displacement curve of each sample is obtained.

Using the critical load corresponding to the moment of failure of each sample (FS), the $K-IC$ fracture toughness value of dental composite samples was calculated from Equation (2.2). (Table 4)

$$K_{IC} = f\left(\frac{h}{w}\right)\frac{F_S}{t\sqrt{w}} \times MPam^{\frac{1}{2}} \tag{2.2}$$

where $f(h/w)$ is a geometric coefficient that depends on the type of part and applied loading. This coefficient is calculated by finite element modeling of the tested piece for the conditions of $s/w = 3.3$ and $h/w = 0.5$. Also, t is the thickness of the sample (mm) and w is the width of the sample (mm). (relation (2.3))

$$f\left(\frac{h}{w}\right) = \frac{\left(2+\frac{h}{w}\right)\left(0.886+4.64\frac{h}{w}-13.32\frac{a^2}{w^2}+14.72\frac{h^3}{w^3}-5.6\frac{h^4}{w^4}\right)}{\left(1-\frac{h}{w}\right)^{\frac{1}{2}}} \tag{2.3}$$

3 Results and discussion

3.1 SEM test

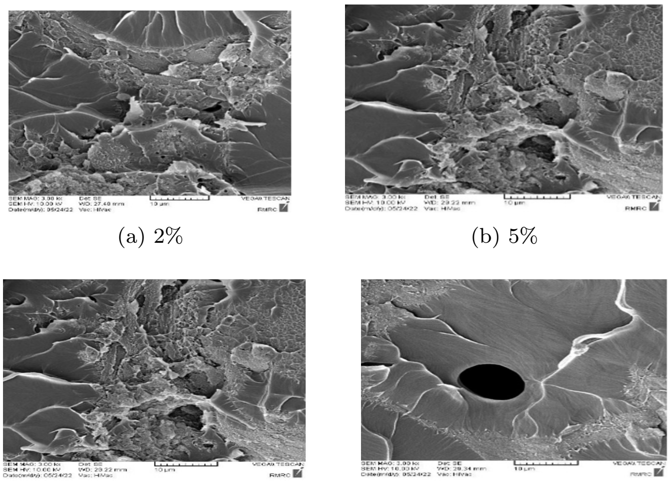
Scanning electron microscope images taken from the surface of samples with different weight percentages show that up to 7% filler weight, nanoparticles in the first group (modified silica) significantly compared to the second group (silica Unmodified) have a uniform distribution on the surface of the base matrix, but at 10% by weight of filler both in the first group and the second group, the distribution of nanoparticles is not uniform and a large number of agglomerates are formed on the surface of the matrix. The formation of agglomerates is due to the presence of hydroxyl groups on the surface of silica nanoparticles, which prevents the proper bonding of the base polymer (PMMA) with silica nanoparticles.

Although the modification of the surface of silica nanoparticles has caused their uniform distribution on the surface of the polymer, the SEM images show that with the increase in the filler percentage, we still see the accumulation of nanoparticles and the formation of agglomerates in some parts of the first group composite surface.

3.2 Moisture absorption

Polymeric composites filled with hard mineral particles in micro or nano dimensions show different behaviors with increasing percentages of particles. Water absorption in the polymer is the result of the molecular polarity of the polymer and unsaturated bonds of molecules or unbalanced intermolecular forces in polymers. According to the ISO 1567 standard, water absorption for thermal and self-baking materials should not exceed 32 micrograms per cubic millimeter.

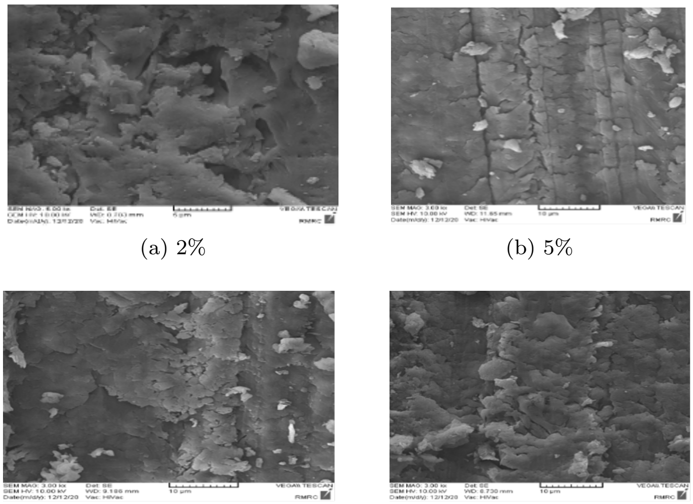
For each weight percentage of the filler, we performed the test three times and obtained the average results for both groups of samples. The amount of moisture absorption in the samples of the first group (table 2) and the second group (table 3) shows that with the increase in the percentage of nano-silica (modified and unmodified), the amount of moisture absorption in the samples decreases, the reason for this can be attributed to the structure Amorphous and shapeless polymer has a related background. The distance between PMMA molecules in the case without silica filler particles is greater than in the case where nanoparticles are added, in fact, silica nanoparticles fill the empty space between the molecules, so that the more the amount of nano-silica in the base polymer increases, the distance between the molecular weight is reduced, the structure of the polymer is more regular, and as a result, the amount of moisture absorption decreases. The results of the experiments also show that we have the lowest amount of moisture absorption at 10 percent by weight of nano silica. Also, the comparison of the amount of moisture absorption for samples produced with modified and unmodified silica nanoparticles shows that the modification of silicon does not



(a) 2% (b) 5%

(c) 7% (d) 10%

Figure 2: Modified silica filler with different percentages



(a) 2% (b) 5%

(c) 7% (d) 10%

Figure 3: Unmodified silica filler with different percentages

affect the amount of moisture absorption. on the other hand, by comparing the samples placed at different pH, we found that as the pH of the liquid bath becomes neutral, the amount of absorption increases in both groups. The highest amount of moisture absorption for different pH is $pH = 7$. The chemical structure of PMMA shows that the base polymer atoms do not tend to react to acidic and basic solvents, and as a result, by being placed in these environments, the amount of absorption in them decreases. They don't react with acids and bases. As a result, we can see that the more we move towards the acidic and alkaline side of the liquid, the amount of absorption decreases. (Figures 4 and 5)

3.3 Fracture toughness

The fracture toughness of a material shows the resistance of that material against crack propagation when it is subjected to loading and is directly dependent on the total energy absorbed to change the plastic shape. The fracture section of the sample after loading is shown. (Figure 6)

In this step, we loaded the samples of the moisture absorption stage. For each weight percentage of silica filler, the experiment was repeated three times and the results were averaged. Tables 4 and 5 show the results of loading samples. Examining the results of the experiment shows that increasing the amount of filler both in modified silica

Table 2: Moisture absorption rate of the samples in the first group (in g/m_3)

pH sample	5	6	7	8	9
A	0.0174 g/m^3	0.0239 g/m^3	0.0644 g/m^3	0.0196 g/m^3	0.0177 g/m^3
B_1	0.0152 g/m^3	0.195 g/m^3	0.0310 g/m^3	0.0095 g/m^3	0.0075 g/m^3
C_1	0.0146 g/m^3	0.189 g/m^3	0.0189 g/m^3	0.0092 g/m^3	0.0070 g/m^3
D_1	0.0123 g/m^3	0.188 g/m^3	0.0167 g/m^3	0.0087 g/m^3	0.0066 g/m^3
E_1	0.0023 g/m^3	0.0014 g/m^3	0.0059 g/m^3	0.0046 g/m^3	0.0033 g/m^3

Table 3: Moisture absorption rate of the samples in the second group (in g/m^3)

pH sample	5	6	7	8	9
A	0.0174 g/m^3	0.0239 g/m^3	0.0644 g/m^3	0.0196 g/m^3	0.0177 g/m^3
B_2	0.0158 g/m^3	0.0199 g/m^3	0.0317 g/m^3	0.0087 g/m^3	0.0066 g/m^3
C_2	0.0153 g/m^3	0.0177 g/m^3	0.0179 g/m^3	0.0083 g/m^3	0.0063 g/m^3
D_2	0.0128 g/m^3	0.0175 g/m^3	0.0159 g/m^3	0.0076 g/m^3	0.0056 g/m^3
E_2	0.0028 g/m^3	0.0019 g/m^3	0.0048 g/m^3	0.0039 g/m^3	0.0027 g/m^3

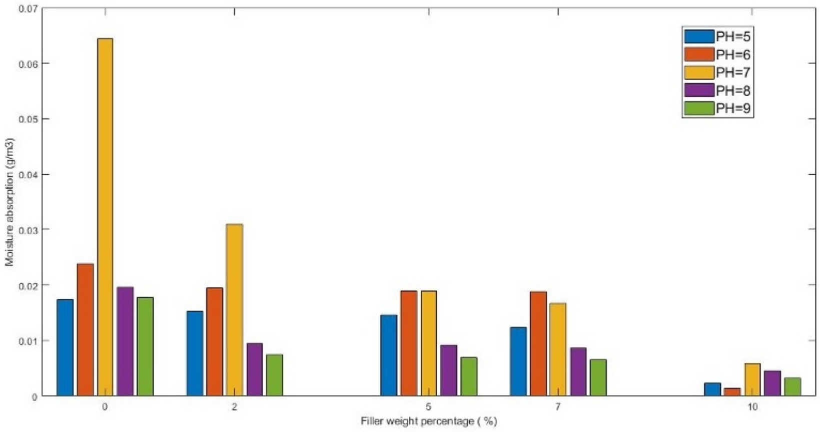


Figure 4: Comparison of the amount of moisture absorption for samples at different pH for the first group

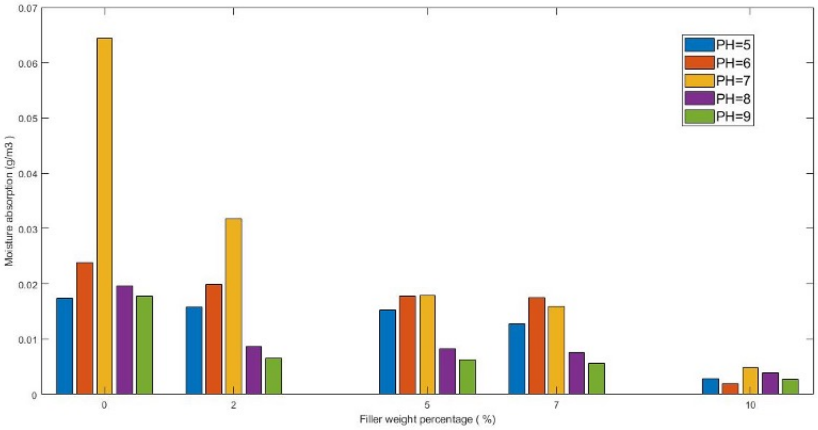


Figure 5: Comparison of the amount of moisture absorption for samples at different pH for the second group

and unmodified silica has increased the fracture toughness of the samples, but in the first group, when the amount of filler is more than 5% by weight, not only the fracture toughness does not improve, but it starts to decrease so that in the case of 10% by weight of modified silica, the fracture toughness of the samples is lower than the samples without silica filler. In the second group, when the amount of unmodified silica filler exceeds 2% by weight, the fracture toughness begins to decrease, so that at 7% by weight of the filler, the fracture toughness is lower than when we did not use silica filler. Since polymers have an amorphous and irregular structure, the increase of filler particles reduces the distance between particles, and this factor reduces the speed of crack growth, and the lengthening of the crack growth path leads to an increase in the fracture toughness of the composite. The smaller the size of the filler particles and the better their surface modification, the higher surface energy is created at the interfacial surface of the filler and leads to improved bending strength. Also, the addition of nanoparticles improves hardness because solid mineral particles usually have higher hardness than polymeric matrices. The researchers believe that the reason for increasing the fracture toughness of composites due to the addition of filler is due to the interaction of the crack tip with the filler phase. On the other hand, with the increase in the amount of filler, the accumulation of particles increases and causes the formation of agglomerates [8, 20]. This phenomenon occurs much earlier for unmodified silica nanoparticles than for modified silica nanoparticles, which causes the acceleration of crack growth, followed by reduced fracture toughness in the samples of the second group compared to the samples of the first group. At high weight percentages for both modified and unmodified silica, excessive accumulation of nanoparticles due to the increase in filler percentage creates agglomerates. Agglomerates act as weak areas in the polymer matrix and collapse in the presence of applied load, which causes the initial failure of the material and, as a result, the reduction of fracture toughness. In addition, the presence of agglomerates in the polymer matrix leads to the contraction of the contact area and the formation of defects. This phenomenon prevents the effective transfer of the applied load from the matrix to the filler nanoparticles, which leads to the inevitable reduction of the fracture toughness of the composite material. However, surface modification of nanoparticles effectively improves the uniform dispersion of nanoparticles in the base polymer matrix, and as long as the concentration of nanoparticles is low (less than 7%), surface modification can have a positive effect on increasing fracture toughness. Therefore, the fracture toughness in composites is a complex process and its increase or decrease cannot be considered to be only affected by the amount of fillers. The study on the mechanism of fracture in composites shows the type of filler, the fracture process, the protrusion and thickness of the crack tip, and the yield point of plastic. The matrix, the structure of the composite, the separation of the interface between the particles and the matrix, and especially the presence of the accumulation of filler particles are among other factors that can affect the results of the fracture toughness test of composites.

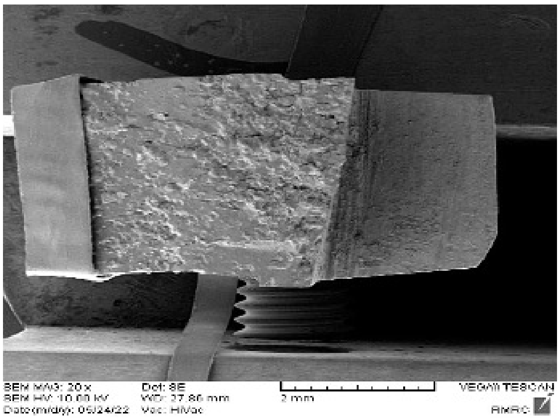


Figure 6: Fracture section of the sample

Table 4: The results of the three-point bending test for the first group

Sample	$F(N)$	$K_{IC}(M_{pa}/\sqrt{m})$
A	140.97	66.25
B_1	151.83	70.97
C_1	221.97	104.3
D_1	175.16	82.32
E_1	119.9	56.35

Table 5: The results of the three-point bending test for the second group

Sample	$F(N)$	$K_{IC}(M_{pa}/\sqrt{m})$
A	140.97	66.25
B_2	144.75	68.98
C_2	142.35	67.83
D_2	107.22	51.01
E_2	88.65	42.15

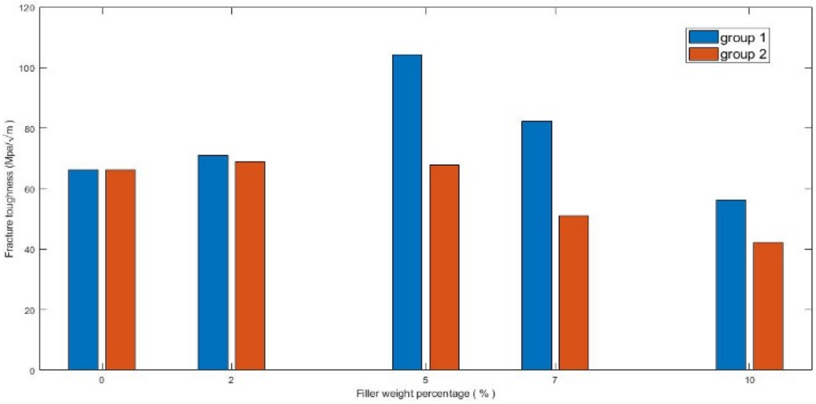


Figure 7: Fracture toughness for samples with different filler percentages for the first and second groups

4 Conclusion

In this research, we have experimentally investigated the effect of adding modified and unmodified silica nanoparticles on the mechanical properties and also the amount of moisture absorption of PMMA-based dental samples.

1. Increasing the percentage of filler (modified and unmodified) causes the accumulation of nanosilica particles, followed by the formation of agglomerates so that the highest amount of agglomerates is observed in composites with 10% by weight of nanosilica.

2. Modifying the surface of silica nanoparticles up to 7% by weight of the filler causes their uniform distribution on the surface of the base polymer in comparison with unmodified silica nanoparticles, as a result, the formation of agglomerates is reduced by modifying the surface of the filler up to 7% by weight of the filler.

3. Increasing the amount of modified silica filler improves the fracture toughness, but there is an optimal limit for this increase, so that an increase of more than 5% by weight of the filler makes the slope of the fracture toughness graph negative, and after the optimal state (5% by weight of the filler) Increasing silica filler reduces the fracture toughness of composites. So in 10% by weight of silica filler, not only the toughness is not improved, but it is lower than the case where PMMA does not have silica filler.

4. Increasing the amount of unmodified silica filler up to 2% by weight improves the fracture toughness, but as the percentage of filler increases, the fracture toughness decreases, so that at 7% by weight of the filler, the fracture toughness is lower than when we did not use the filler.

5. The increase in filler leads to a decrease in moisture absorption in both groups. As the amount of silicon in the base polymer increases, the amount of moisture absorption also decreases, so that in the case of 10 percent by weight of the filler, we have the lowest amount of moisture absorption.

6. There was no significant difference in the amount of moisture absorption between the samples produced with modified and unmodified silica, therefore, modification of the surface of silica nanoparticles does not affect the amount of moisture absorption.

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