

Assessment of Some Properties of Heat Activated Denture Base Resin Reinforced with Strontium Titanate Nano Powder

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ABSTRACT

Introduction: In the current research, evaluation of some properties of heat cured acrylic resin were carried out after adding different concentration of strontium titanate (SrTiO_3) nano powder (1% and 1.5% wt.).

Statement of the problem: Polymethyl Methacrylate (PMMA) is the most often utilized material for dentures manufacturing. Insufficient thermal conductivity, poor surface hardness, increase in roughness values and reduced some mechanical qualities make this material far from optimal in terms of justifying mechanical requirements.

Aim of the study: The goal of this research was to investigate the effects of adding SrTiO_3 (NPs) nanoparticles in proportion of 1% wt. and 1.5% wt. on some physical and mechanical properties of heat cured denture base material.

Materials and methods: One hundred twenty (120) samples were divided into four groups based on the testing property, each group had 30 specimens, which were then divided into three groups: Control group, reinforced PMMA (1% wt. and 1.5% w SrTiO_3 nanoparticles).

Impact strength, transverse strength, vickers hardness test and surface roughness were all tested. Additional tests include Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR).

Result: FTIR revealed no chemical interaction between SrTiO_3 NPs and acrylic resin. The results of this study showed at 1.5% wt. SrTiO_3 highly significant increase in impact strength and vickers hardness, while for transverse strength the 1% wt. showed highly significant increase while there was non-significant decrease in surface roughness.

Conclusion: The addition of SrTiO_3 nanoparticles into denture base acrylic material improve impact strength, transverse strength, surface hardness values, while there was non-significant reduction in surface roughness.

Key words: Acrylic resin, Strontium titanate (SrTiO_3), Impact strength, Vickers hardness

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INTRODUCTION

The fundamental purpose of dentistry is to retrieve or replace tooth structure that has been lost or destroyed, in order to meet the patient's functional and cosmetic needs. Dentures, which are produced from resin based polymeric systems, are still the most prevalent prosthetic appliance [1].

Polymethyl Methacrylate (PMMA) is a widely utilized polymer because of its optical characteristics, biocompatibility and good look, despite this, PMMA's mechanical characteristics against fatigue, impact and bending are poor, these difficulties must be addressed in order to improve the performance of PMMA as a denture base material [2].

Transverse strength is utilized more often than tensile and compressive strength measures because it strictly reflects the kind of loading that the denture is subjected to inside the mouth and is produced when stress is used in the middle of a beam that is supported at both ends [3].

A variety of strategies have been used to improve mechanical qualities, involves chemically correcting polymeric structure by the addition of specific components.

Another method for improving acrylic resin is to add particles and fibers. Fillers of micrometer and nano scale size are commonly added to polymers to increase stiffness and strength, improve solvent resistance, or lower costs [4].

It was found that adding nanoparticles as a reinforcing agent affects the physical properties of acrylic resins [5]. The chemical formula of strontium titanate (SrTiO_3) is an oxide of strontium and titanium. It's a popular material for super conductors and thin oxide sheets. Strontium titanate nano powder can be used in making scaffolds for bone regeneration [6].

MATERIALS AND METHODS

In this study, strontium titanate nano powder (nano shel, USA) (average particle size 80-100 nm) and heat cure acrylic resin (Kulzer, Germany) were used.

Pilot study

Various weight concentrations (0.5%, 1%, 1.5% and 2 %) of SrTiO₃ were incorporated into heat cure acrylic resin; impact strength and transverse strength were compared. As a result, the weight percentages of 1% and 1.5% were chosen because they presented the best behavior.

Specimen grouping

In this research, a total of 120 samples were prepared. According to the tests employed, the samples were divided into four different groups, with each test containing 30 samples that were further subdivided into three groups:

- 10 samples of acrylic resin without SrTiO₃ nanoparticles as a control group.
- 10 samples of acrylic resin with 1% SrTiO₃ nanoparticles.
- 10 samples of acrylic resin with 1.5% SrTiO₃ nanoparticles.

Mold fabrication

Different plastic patterns were created to build molds for study samples. These models were completed by laser cutting a plastic plate into the correct form and dimension based on the test specifications. The mold is then prepared in the same way that complete dentures are processed to manufacture acrylic specimens. The separating medium (cold mold seal) is applied to the plastic patterns and allowed to dry. The dental stone is combined according to the manufacturer's instructions (100 g powder to 20 ml water) and poured into the flask's lower half, which is then vibrated to remove any air bubbles. The patterns were inserted about halfway into the stone, which was then dried. This is followed by covering the lower half was covered with separating material and let to dry, at that moment the upper half has been put and filled with stone and it has been vibrated and finally the flask's lid is placed and left to dry. After the stone has set, the two halves of the flasks are split and the plastic patterns were detached to produce a mold hole for the acrylic specimen. The separating media is then applied and allowed to dry and the flask is ready to pack the acrylic specimen in the traditional fashion.

The tests that were carried out during the research

A-Transverse strength

Test specimen: The dimensions of the specimens utilized in this test were (65 mm x 10 mm x 2.5 mm) (Figure 1). Before being tested, all specimens were maintained in distilled water at 37°C for 48 hours [7].

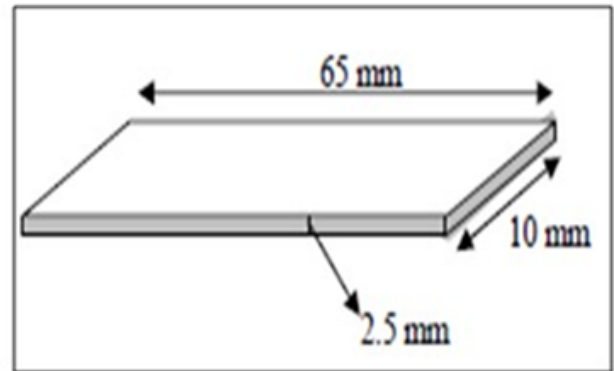


Figure 1: Transverse strength, surface hardness and surface roughness specimen dimensions.

Test procedure: An instron testing machine WDW-200 E (UK) (Figure 2). The specimens were placed on bending fixtures made of two parallel supports (50 mm) apart, and the load was applied at a rate of 1 mm/min through a rod that was positioned in the middle of the supports to cause deflection until fracture occurred. The transverse strength was determined using the formula below (1):

$$T = 3PL / 2bd^2 \dots\dots\dots (1)$$

Where,

T: Transverse strength (N/mm²);

P: Maximum load applied on sample (N);

L: Distance between supports (mm);

b: Width of specimens (mm);

d: Depth of specimens (mm).

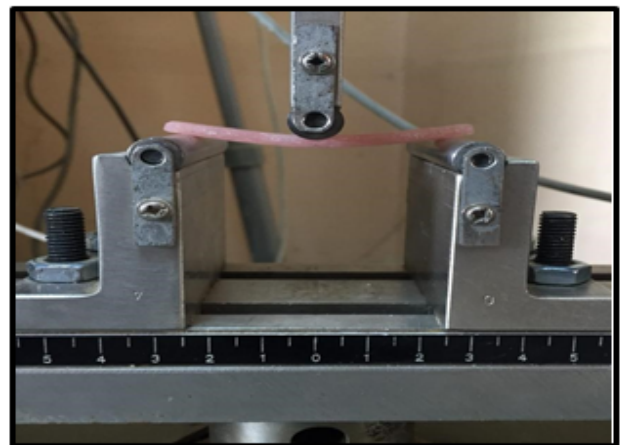


Figure 2: Instron universal testing machine.

Impact strength

Test specimens: For the impact strength test, acrylic resin specimens with dimensions of (80 mm x 10 mm x 4 mm) were made. The impact strength test was carried by using charpy's impact testing device (testing machines Inc., USA) (Figure 3) and in accordance with the procedure recommended by ISO 179-1: 2000.

Each specimen was held horizontally at both end and stuck with a pendulum of 2 Joules (TMI, testing machine

Inc., Amity Vielle, New York, USA). The impact energy was measured in Joules (Figure 3).

The impact strength was calculated in Joules per square meter by the following formula (2):

$$\text{Impact Strength} = (E/bd) \times 10^3 \dots\dots (2)$$

Where,

E: The impact energy in Joules;

b: The width of specimens in millimeters;

d: The depth of specimens in millimeters.



Figure 3: Impact strength test (Charpy's impact testing device).

Surface roughness

Test specimen: For the surface roughness test, test specimens of acrylic resin were made with dimensions of (65 mm x 10 mm x 2.5 mm) as shown in Figure 1.

Testing procedure: Profilometer (TEREN, DaLian, China) was used to investigate the micro geometry of test specimens). This apparatus uses a surface contact analyzer (a diamond tipped stylus) to track the progression of surface imperfections (Figure 4). The stylus can capture all peaks and recesses at a maximum distance of 11 mm. The specimens were divided into three regions and the analyzer was moved along the tested area to calculate the average of three readings.



Figure 4: Profilometer.

Vickers hardness test

Test specimen: The specimens utilized in this study were tested with the following dimensions (65 mm length x 10 mm width x 2.5 mm thickness) as shown in Figure 1.

Testing procedure: All imperfections were eliminated with a tungsten carbide bur after the specimens were prepared. The samples were polished and placed in distilled water to keep them clean and ready to testing.

The Vickers hardness test was performed with Laryee hvs-5 (manufacturing limited, Beijing, China) (Figure 5). Vickers hardness testing was performed on the specimens with a 25 g load for 30 seconds. Penetration was found in three locations. The average of three readings was determined, with one in the middle and two on either end.



Figure 5: Vickers hardness test.

The statistical analysis: One way ANOVA (Analysis of Variance) and post hoc test (Tukey HSD) software (IBM SPSS Statistics 26 were used in the statistical analysis).

The Probability (P) value of >0.05 were considered statistically Non-Significant (NS), P values of ≤ 0.05 were considered Statistically significant (S) and P values of ≤ 0.01 were considered Highly Significant (HS).

RESULTS

FTIR: The FTIR results of the strontium titanate oxide nano filler powder and the heat cure acrylic resin before and after addition of SrTiO₃ Nano fillers are shown respectively in Figures 6 and 7. The FTIR results revealed no structural differences between the specimens before and after the addition of SrTiO₃.

However, little changes are found which might be related to alterations in the polymerization process.

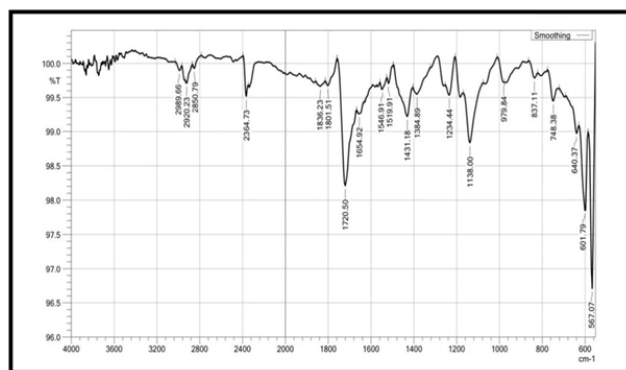


Figure 6: FTIR control specimen.

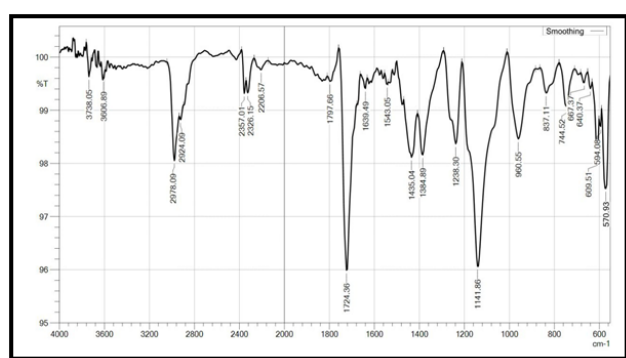


Figure 7: FTIR of specimen after addition of SrTiO₃.

Scanning Electron Microscope (SEM test)

The surface of control and additive samples of impact strength test specimen was examined by SEM with different magnifications power to evaluate dispersions of nanoparticles in the resin matrix as seen in Figure 8. The SEM images showed well dispersion of SrTiO₃ NPs inside the acrylic resin with some aggregation (yellow arrows) as the filler content increases as shown in Figure 8.

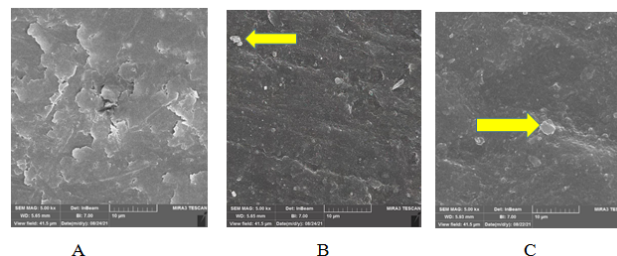


Figure 8: Scanning electron microscope, A) PMMA without nanoparticles; B) PMMA with nanoparticle; C) PMMA with nanoparticle.

Mechanical tests results

Impact strength: The highest mean value of impact strength is related to 1.5% wt. group, while the mean value of control group was the lowest value. Tukey test revealed highly significant difference between all tested groups (Table 1).

Table 1: Descriptive statistics, one way ANOVA and Tukey's HSD of impact strength.

Impact strength					ANOVA		Tukey HSD	
Group	Min	Max	Mean	± SD	F	P value	Groups	P value
Control (A)	9.32	11.50	10.555	0.6467	60.515	0.000	AB	0.000
1% (B)	11.22	13.82	12.531	0.7017			AC	0.000
1.5% (C)	12.96	14.33	13.554	0.4914			BC	0.003
Levene statistics=0.259, p value=0.774 (NS).								

Transverse strength test: The highest mean value is present in 1% wt. SrTiO₃, while the lowest mean value is for control group (Table 2). There was highly significant

difference between groups (A) and (B), groups (B) and (C). While non-significant difference was found between groups (A) and group (B).

Table 2: Descriptive statistics, one way ANOVA and Tukey's HSD of transverse strength.

Transverse strength					ANOVA		Tukey HSD	
Group	Min	Max	Mean	± SD	F	P value	Groups	P value
Control (A)	77.43	87.14	81.133	2.8541	12.756	0.000	AB	0.000
1% (B)	81.79	92.74	86.886	3.3720			AC	0.694
1.5% (C)	79.31	84.90	82.131	1.6459			BC	0.002
Levene statistics=2.164, p value=0.134 (NS).								

Vickers hardness test: The highest mean value is 1.5% wt. SrTiO₃ group, while the lowest value for control

group. There was highly significant difference between all of the groups (Table 3).

Table 3: Descriptive statistics, one way ANOVA and Tukey's HSD of Vickers hardness.

Vickers micro hardness					ANOVA		Tukey HSD	
Group	Min	Max	Mean	± SD	F	P value	Groups	P value
Control (A)	15.02	17.70	16.365	0.7721	47.117	0.000	A B	0.000
1% (B)	18.23	20.60	19.171	0.7961			A C	0.000
1.5% (C)	18.87	22.46	20.565	1.2975			B C	0.010
Levene statistics=2.307, p value=0.119 (NS)								

Surface roughness test: The control group showed the highest mean value, while 1.5% wt. Nano SrTiO₃ showed the lowest mean value (Table 4).

Table 4: Descriptive statistics, one way ANOVA and Tukey's HSD of surface roughness.

Surface roughness test					ANOVA	
Group	Min	Max	Mean	± SD	F	P value
Control (A)	0.97	1.82	1.4344	0.24105	0.781	0.468
1% (B)	1.16	1.71	1.3862	0.1575		
1.5% (C)	1.05	1.76	1.3232	0.19107		
Levene statistics=2.307, p value=0.119 (NS)						

DISCUSSION

The study's findings revealed that the 1.5% wt. group had the highest impact strength value when compared to the 1% wt. and control groups. This is because the new combination (SrTiO₃+PMMA), enhance the internal resistance due to force exchange between matrix and filler. The applied pressures re also transferred to the nanoparticles, increasing the impact strength [8]. Furthermore, the compound stress strain behavior is influenced by particle size and bonding interaction [9]. The addition of SrTiO₃ nano fillers to the acrylic resin may cause limitation the mobility and deformation of the matrix by introducing a mechanical restriction. This result was in agreement with Safi who incorporated ZrO₂ nano fillers into heat cured (PMMA) [10].

In the transverse strength, it was found that (1% and 1.5% group higher than control group) because of the use of nanoparticles reduces the free space distance between polymer chains during the curing process, resulting in more complex network chain [11,12]. The increase in transverse strength with SrTiO₃ Nano filler could be attributable to stress transference from the more flexible polymers to the high modulus (more rigid and stiffer) filler particles [13].

For the hardness test, the polymer is strengthened with SrTiO₃ showed higher surface hardness may be due to good distribution in the resin matrix, the distance between the particles inside the matrix will be decreased [14]. The bonding strength between the particles rises as the inter particle distance decreases, causing hard material particles SrTiO₃ to accumulate on the surface of the acrylic matrix spaces, resulting in better hardness behavior [15]. The improved hardness could be attributed to better nano filler dispersion in the resin

matrix and the buildup of SrTiO₃ nano particles, a hard material, in the polymer matrix. The 1.5% wt. Nano SrTiO₃ increased in hardness more than the 1% wt. nano SrTiO₃ due to higher nano filler accumulation in the resin matrix [16].

Finally, for surface roughness test, non-significant change with different percentages of added SrTiO₃ nanoparticles and this may be due to that the SrTiO₃ nanoparticles have very small size, also, because the surface roughness test is concerned with the outer surface of the nano composite rather than the inner surface, just a few particles were implicated on the surface of the specimens when a tiny fraction of nanoparticles was added to the acrylic resin [17,18].

CONCLUSION

Within the limitation of this study, it can be concluded that, the impact strength, transverse strength and surface hardness were significantly increase in the reinforced SrTiO₃ group while surface roughness of acrylic denture base reinforced by SrTiO₃ nanoparticles showed non-significant decrease among the study groups.

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