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RESEARCH ARTICLE

Effect of zinc oxide nanoparticle concentration coated on acrylic resin upon surface roughness and abrasion resistance

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ABSTRACT

Acrylic resin is the material most often used as a base for dentures; however, acrylic resin has shortcomings in its biological properties as it does not have antimicrobial properties. ZnO is added to acrylic resin because of its antimicrobial properties. The aim of this research is to determine the effect of the concentration of ZnO nanoparticles as a heat polymerization acrylic resin coating on the coating's resistance to abrasion. A total of 24 acrylic resin samples were made, each measuring 13 x 13 x 2 mm. The acrylic resin was coated with 3-(trimethoxysilyl)propyl methacrylate), then with ZnO nanoparticles with varying concentrations of 2.5%, 5%, and 7.5% in ethanol. ZnO nanoparticle coating was applied using the dip coating method. Subsequently, the samples were subjected to an initial roughness test, abrasion test, and final roughness test. The data obtained were analyzed using one-way ANOVA and $LSD_{(0.05)}$. The results showed that the mean change in roughness (μm) and standard deviation for groups I to IV were 0.11 ± 0.13, 0.08 ± 0.33, 0.1 ± 0.12, and 0.19 ± 0.15, respectively. The results of the one-way ANOVA test showed that there was no significant difference in the roughness after the abrasion test ($p > 0.05$). Thus, zinc oxide nanoparticles can reduce surface roughness and are resistant to surface abrasion.

Keywords: abrasion; coating; heat polymerization acrylic resin; surface roughness; ZnO nanoparticles

INTRODUCTION

Tooth loss is a dental and oral health problem that many Indonesian people suffer from.[1] Caries and periodontal disease are the main causes of tooth loss, resulting in a decrease in the ability of mastication, speaking, and overall esthetics. Tooth loss may encourage someone to make artificial teeth to restore the function of lost teeth.[2]

Denture bases can be made of metal or non-metal (polymer) materials. Polymer materials are commonly used because they are easy to manipulate, light, having good stability in the oral cavity, low dimensional changes, resistant to abrasion, low surface hardness, non-toxic, affordable price, and colors that resemble the oral mucosa.[2] The polymer material mostly used as a denture base is heat polymerized acrylic resin. However, this material has disadvantages in biological properties because it does not have antimicrobial properties. Oral microbials, such as *Candida albicans*, are easy to adhere and proliferate on to denture acrylic surface. This condition can lead to denture stomatitis.[3]

Modification of heat polymerization acrylic resin with antimicrobial agents have been conducted recently. The antimicrobial agents are mixed into acrylic resins as a filler or coating on resin acrylic surface. An addition of ZnO nanoparticles of 2.5%, 5%, and 7.5% to heat polymerized acrylic resin showed an increase in the antimicrobial properties towards *C. albicans*, with the most effective antimicrobial properties observed at a ZnO nanoparticle with a concentration of 7.5%.[4] Modification of polymethylmethacrylate with silanized ZnO nanoparticles with concentrations of 1.25%, 2.5%, and 5% showed a greater reduction in *C. albicans*. The best antimicrobial properties were found in ZnO with a concentration of 2.5%. Nevertheless, ZnO as a filler for acrylic resin has its drawbacks due to the occurrence of particle agglomeration which can cause reduced physical, antimicrobial properties, and reduced transparency of the acrylic resin.[5]

Mixing methods can change the chemical structure of acrylic, thereby risking reducing its mechanical properties and reducing its color stability.[5] Antimicrobial agents, such as titanium oxide, aluminum oxide, or zinc oxide nanoparticles (ZnO NP), have been used in modification of acrylic resins.[6] Coating of heat polymerization acrylic resin with antimicrobial agents can be done using the dip-coating method.[7]

One indicator of the success of coating ZnO nanoparticles on heat polymerized acrylic resin is that the coating does not easily lose off from the surface of the acrylic resin.[8] Abrasion is the loss of material caused by a low ability to resist scratches which will result in the exposure of material particles and internal porosity. Materials that do not have good abrasion resistance indicate that they will not last long in the oral cavity and increase surface roughness. Increased surface roughness can cause accumulation of debris and plaque on the surface of the material, thus becoming a risk factor for infection in the oral cavity.[2] The aim of this research is to determine the effect of the concentration of ZnO nanoparticles coated on heat polymerization acrylic resin on roughness and abrasion resistance.

MATERIALS AND METHODS

This research was carried out after obtaining ethics approval from the Ethics Committee of the Faculty of Dentistry, Universitas Gadjah Mada (project no. 43/UN1/KEP/FKG-RSGM/EC/2023). This research was conducted at the Integrated Research Laboratory of Faculty of Dentistry, Universitas Gadjah Mada and the Mechanical and Industrial Engineering Laboratory in the same university. The main materials and tools for this research were heat polymerized acrylic resin, ZnO nanoparticles, 3-(trimethoxysilyl)propyl methacrylate, electric toothbrush (Oral B, China), and surface roughness tester (Starret, USA).

Table 1. Variation consentration coating ZnO

Group (% ZnO)	Material coating (ZnO nanoparticle in ethanol) (%b/v)
I	0%
II	2.5%
III	5%
IV	7.5%

Twenty-four acrylic resin samples were made with a dimension of 13 mm x 13 mm x 2 mm. Acrylic resin was processed according to product instruction with a ratio of 22 g of powder and 10 ml of liquid acrylic resin. The acrylic resin powder and liquid acrylic resin were put in the stellon pot and manipulated until they reached the dough phase, then put into a flask mold. The acrylic samples in the flask were polymerized using a curing unit at a temperature of 74 °C for 1 hour and 90 °C for 30 minutes. Next, the acrylic resin samples were cleaned, the excess was removed using a stone bur with a low-speed rotary instrument, and the dimensions were measured using sliding calipers.[2]

Acrylic resin samples were coated with ZnO nanoparticles with varying concentrations of 0%, 2.5%, 5%, and 7.5% in ethanol (Table 1). Using a digital scale, ZnO nanoparticle powder was weighed at 2.5 grams, 5 grams, and 7.5 grams for groups II to IV sequentially. Ethanol as a solvent was measured using a measuring cup with a volume of 100 ml, then poured into a glass beaker, and ZnO nanoparticle powder was added. Following this, the mixture was stirred using a magnetic stirrer for 30 seconds until a homogeneous solution was obtained. Acrylic resin samples were smeared with silane coupling agent (3-methacryloxypropyl trimethoxysilane) and air-dried. ZnO nanoparticle coating was applied using the dip coating method. The acrylic

Figure 1. Coating process of acrylic resin samples with ZnO suspension in ethanol

resin samples were placed in a petri dish, then a suspension of ZnO in ethanol was poured over the samples until the entire samples were submerged and left for 5 minutes (Figure 1). The samples were transferred into another petri dish, dried in an oven at 70 °C for 10 minutes, and then stored in a closed container.

Initial roughness measurements were carried out using a surface roughness tester (Starrett, SR Series, UK). The sample was placed on the sample table, then the stylus was placed on the sample surface. The tool was turned on until the stylus moved along the surface area of 5 mm long. The surface roughness (Ra) was measured 3 times for each sample, then the average roughness value was calculated.

The coating resistance to abrasion test was carried out by brushing the coating layer on the sample surface using an electric toothbrush for 3 minutes. The sample was placed on an automatic brushing simulation machine holder perpendicular to the long axis of the toothbrush.

The final roughness of the sample was measured again, then the difference in surface roughness after and before the sample brushing treatment was calculated. Abrasion resistance was evaluated by looking at the increase in surface roughness. The greater the change, the lower the abrasion resistance. The data obtained were analyzed using the Shapiro-Wilk and Levene's tests to confirm normality and homogeneity. Then,

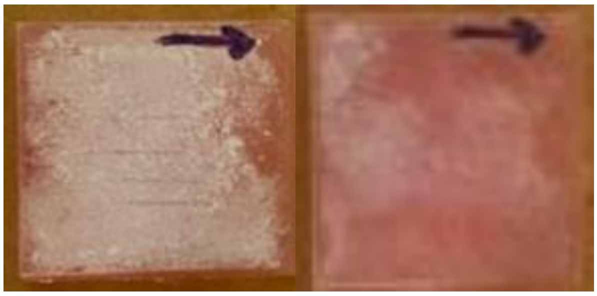

Figure 2. Sample acrylic resin before and after abrasion test

the data were analyzed using one-way ANOVA parametric test and the LSD post hoc test with a significance level of 95%.

RESULTS

This research investigated the effect of zinc oxide nanoparticle concentration as a heat polymerization acrylic resin coating on abrasion resistance. The results of the visual observation showed a reduction in coating coverage on the surface of the acrylic resin after brushing (Figure 2). The results of surface roughness measurements before and after brushing and the magnitude of changes in roughness are presented in Table 2.

As shown in Table 2, the highest average surface roughness value was in the 2.5% ZnO coating group (group II), while the lowest roughness value was in the 5% ZnO coating groups (group III) before and after abrasion tests. The highest change in roughness was in group IV, while the lowest change in roughness was in group II.

Based on the results of the one-way ANOVA (Table 3), there was a significant difference in roughness in the group before the abrasion test (0.002). Meanwhile, there was no significant difference in roughness in the group after the abrasion test (0.099) and in the group the difference roughness before and after the abrasion tests (0.806). The results of the LSD post-hoc analysis (Table 4) showed differences in roughness between group I (0%) and group III (5%), group I (0%) and group IV (7.5%), group II (2.5%) and group III (5%), and group II (2.5%) and group IV (7.5%).

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Table 2. Mean and standard deviation of surface roughness of acrylic resin samples (µm)

Group	Mean ± SD before abrasion test	Group mean ± SD after abrasion test	Mean ± SD roughness difference
I	0.79 ± 0.26	0.90 ± 0.37	0.11 ± 0.13
II	0.98 ± 0.24	1.06 ± 0.35	0.08 ± 0.33
III	0.55 ± 0.13	0.65 ± 0.17	0.10 ± 0.12
IV	0.55 ± 0.05	0.74 ± 0.17	0.19 ± 0.15

Table 3. One way anova test results

Variable	Significancy
Surface roughness before abrasion test	0.002
Surface roughness after abrasion test	0.099
The roughness difference after and before abrasion tests	0.806

Table 4. Group LSD post-hoc test results before abrasion test

Group	I (0%)	II (2.5%)	III (5%)	IV (7.5%)
I	-	0.100	0.043*	0.044*
II	-	-	0.001*	0.001*
III	-	-	-	0.988
IV	-	-	-	-

Note * = Significant difference

DISCUSSION

This research set out with the aim of assessing the effect of zinc oxide nanoparticle coating concentration on the surface roughness of heat polymerized acrylic resin. The results showed that the average value of surface roughness tended to decrease with the increase in concentration of zinc oxide nanoparticle coating on heat polymerized acrylic resin (Table 2). The results of the one-way ANOVA as presented in Table 4 showed that the concentration of zinc oxide nanoparticles exhibited a significant effect on the surface roughness of heat polymerized acrylic resin ($p < 0.05$). In general, this research found that an increase in the concentration of zinc oxide nanoparticles was associated with a reduction in the surface roughness of heat polymerized acrylic resin.

Surface roughness is the irregularity and porosity on the surface of a material. The surface of the acrylic resin base should not be porous and there should be no bubbles on the surface.[9,10] According to ISO 20795-1, the clinically acceptable critical roughness value of an acrylic resin base should be no more than 0.2 µm.[10] In this study, the surface roughness values of all research samples were higher than the threshold value (0.2 µm). The reason for this was that all samples used for testing were not subjected to a polishing procedure in order to imitate the condition of the fitting surface of the acrylic resin base in the oral cavity, as indicated by previous research.[11]

The results of the roughness analysis after the abrasion test showed that the roughness value of the acrylic resin tended to increase due to varying addition of ZnO (Table 2). The results of the one-way ANOVA in Table 4 showed that the concentration of zinc oxide nanoparticles did not have a significant effect on the surface roughness of heat polymerized acrylic resin ($p > 0.05$) after the abrasion test or on the difference in roughness after the abrasion test. The increase in roughness was due to the loss of material matrices because of the low ability to resist scratches which could result in the exposure of material particles and internal porosity. Surface modification of ZnO nanoparticles with a silane coupling agent before the coating procedure can be used to improve the mechanical characteristics of acrylic resin.[6]

The surface roughness of heat polymerized acrylic resin is influenced by particle size, filler concentration, and the use of silane coupling agent.[12,13] Silane coupling agent is coated before coating the ZnO nanoparticles. The aim is to create a good dispersion between the ZnO nanoparticles and the acrylic resin matrix, where the ZnO nanoparticles will fill the gaps between the pores of the acrylic resin matrix and smooth the surface of the acrylic resin.[14] Silane coupling agent plays a role in resisting stress transfer from the organic matrix.[15] Results of the roughness assessment after the abrasion test showed that the roughness value of the acrylic resin tended to increase (Table 2). The results of the one-way ANOVA in Table

4 showed that the concentration of zinc oxide nanoparticles did not have a significant effect on the surface roughness of the heat polymerized acrylic resin ($p > 0.05$) after the abrasion test or on the difference in roughness after the abrasion test. Surface modification of ZnO nanoparticles with a silane coupling agent before the coating procedure can be used to improve the mechanical characteristics of acrylic resin.[6]

An insignificant change in roughness is influenced by the silane coupling agent coating to create a good dispersion between the zinc oxide nanoparticles and the acrylic resin matrix. This allows the zinc oxide nanoparticles to fill the gaps between the pores of the acrylic resin matrix and smooth the surface of the acrylic resin. Silanization of zinc oxide nanoparticles with 3-trimethoxysilyl-propyl methacrylate will make the functional groups reactive and provide a large interfacial area for the zinc oxide nanoparticles, thus increasing the bond between the acrylic resin and the zinc oxide nanoparticles.[16] Based on research conducted by Maharani, there was a decrease in surface roughness on acrylic resin coated with silica coating using the dip coating method.[17] Acrylic resin coating using TiO_2 shows that the TiO_2 layer increases the abrasion resistance of the acrylic resin surface.[18] This study found that the durability of the zinc oxide nanoparticle coating on acrylic resin was good because the increase in roughness of the acrylic resin was not statistically significant.

CONCLUSION

The results of this research indicate that zinc oxide nanoparticle coating can reduce surface roughness and is resistant to surface abrasion.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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