Original Research

Comparative Evaluation of the Flexural Strength of Heat Polymerized Acrylic Resin with the Addition of 8% and 13% Aluminum Oxide Powder: An In-vitro Study

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Abstract

Introduction: Acrylic resins have been used successfully as denture bases. However, acrylic resin denture base materials are brittle and have poor strength and thermal conductivity. Therefore, it is essential to improve the flexural strength of heat polymerized acrylic resin. The present study aimed to evaluate and compare the flexural strength of heated polymerized acrylic resin with the addition of 8% and 13% aluminum oxide powder. **Methods:** In total, 90 acrylic specimens were fabricated and divided into three groups of A1 (unmodified heat-cured denture base resin), A2 and A3 (heat-cured denture base resin polymer modified with 8% and 13% by weight of aluminum oxide powder, respectively). The specimens were stored in distilled water for one week, and flexural strength was assessed using a universal testing machine. Data analysis was performed using one-way analysis of variance (ANOVA). **Results:** Comparison of groups A1 and A2 (8%) showed the highest flexural strength (85.94 MPa) in group A2. A significant increase was observed in the values of flexural strength with 13% alumina addition. Comparison of groups A1 and A3 (13%) showed the highest flexural strength (86.41 MPa) in group A3, and the difference in the mean values of flexural strength was considered significant. Moreover, comparison of groups A2 and A3 indicated the highest flexural strength in group A3. **Conclusion:** Addition of alumina to conventional heat-cured acrylic resin shows increase in flexural strength. Increasing the flexural strength of acrylic resin base materials could results in higher clinical success rate.

Keywords: Conventional Heat-cured Denture Base Resins, Flexural Strength, Aluminum Oxide Powder, Polymethyl Methacrylate.

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Introduction

Acrylic resin and rubber-reinforced acrylic polymers represent approximately 95% of the denture base materials used in Prosthodontics (1). Despite the tremendous progress in dentistry, tooth loss remains unavoidable, necessitating replacement by artificially fixed or removable substitutes. The search for an ideal denture base material remains a challenge to dentists, specifically in the treatment of completely edentulous patients, and there is ongoing research to develop ideal denture base materials that could address the challenges in the oral environment.

Acrylic resins have been used successfully as denture bases owing to their ease of processing, cost-efficiency, light weight, and color matching ability (2). However, acrylic resin denture base materials have poor strength and low thermal conductivity, while they are also brittle (3, 4).

Since the introduction of polymethylmethacrylate (PMMA) as a denture base material in the 1930s, PMMA has gained more popularity compared to other denture base materials owing to advantages such as good aesthetics, biocompatibility in the oral environment, and ease of manipulation and processing. On the other hand, this material does not fulfill all the desirable properties of a denture base material due to limitations such as the brittle nature and low thermal conductivity. Therefore, it is appropriate to increase the strength parameters and thermal conductivity of PMMA (5).

Strength parameters are essential to the long service of prosthesis inside the oral environment, as well as the bearing of masticatory forces. The most common tests in this regard are impact strength, which is the ability of a material to resist a sudden, high-level force, and shock and flexural strength, which measures the force required to deform the material to fracture or irreversible yield. Due to the risk of denture fracture, high impact strength is considered to be a desirable property. Incorporating the mentioned properties in denture base materials would help resist torsional forces, thereby leading to longer clinical service of the prosthesis (6).

Thermal conductivity is required for perceiving hot and cold sensations, better appreciation of taste, and minimizing the perception of the denture as a foreign body. With commercially available denture base resins, there is the lack of thermal stimulation to the underlying mucosa, which leads to the reduction of stratum corneum thickness, predisposing the mucosa to injuries due to the functioning of the denture (7).

To date, several attempts have been made to improve the mechanical properties and thermal conductivity of heat-cured denture base acrylic resin, including the chemical modification of PMMA and addition of various reinforcing materials. Chemical modification of PMMA could be performed with the addition of a rubber graft copolymer and reinforcement of PMMA with other materials (e.g., carbon fiber, aramid fibers, glass fiber, and ultra-high modulus polyethylene) (8).

In 2008, Ellakwa, Ayman, Mohamed, and Ali (6) investigated the effects of additional aluminum oxide powder at various concentrations (5-20%) based on weight, as well as the effects of flexural strength and thermal diffusivity of heat polymerized denture base resin. After the analysis of the samples, it was concluded that there was an increase not only in the flexural strength with the reinforcement of the resin samples with aluminum oxide powder, but such enhancement was also observed in thermal diffusivity. It is also notable that the addition of metal fillers not only provides the advantage of improved strength and thermal conductivity, but it also reduces polymerization shrinkage and warpage, makes the material radiopaque, and inhibits bacterial growth on the denture surface.

Due to the allergic reaction caused by metallic denture base materials, an insight into acrylic-based materials with improved thermal diffusivity is of interest. One approach for the enhancement of the thermal diffusivity of denture base acrylic resins is introduction of a more thermal-conducting phase within the insulating acrylic resin matrix, which causes development of a composite denture base material. Another approach involves the addition of thermal-conducting metal particles to the powder or liquid resin and polymerize in accordance with the instructions of the manufacturer, which results in a modest increase in thermal conductivity (9). However, a significant increase in thermal conductivity using this approach requires the higher loading of the metal powder, which alters some of the beneficial characteristics of acrylic resins, such as density, tensile strength, toughness, and diminished esthetic appearance.

Aluminum oxide, which is commonly referred to as alumina, possesses strong ionic interatomic bonding properties, as well as better material characteristics. Aluminum is found in several crystalline phases and could revert to the most stable hexagonal alpha phase at higher temperatures, which is of particular interest in structural applications. Alpha-phase alumina is the strongest and stiffest of all oxide phases, which is associated with remarkable hardness, dielectric properties, refractoriness, and thermal properties (7).

Evidence is scarce regarding the effects of the percentage and particle size of the metal fillers used for the reinforcement of denture base resin, and no studies have been focused on the effects of metal fillers on the reinforcement of commercially available high-impact denture base resin.

The present study aimed to evaluate and compare the flexural strength of conventional heat polymerized acrylic resin reinforced with aluminum oxide powder with the addition of 8% and 13% aluminum oxide powder. The research hypothesis was that the addition of aluminum oxide with a higher percentage will increase the flexural strength of heat polymerized acrylic resin.

Materials and Methods

1. Metal Mold Fabrication

To standardize the samples, a standard stainless steel master die with rectangular mold spaces (diameters of each mold: 42*12*3 mm^3) was fabricated in order to generate rectangular specimens. Two stainless steel square blanks of the similar size were also fabricated (e.g., upper member and lower member of the flask assembly). In addition, three knobs were fabricated to the lower member, so that the standard stainless-steel master die could be sandwiched between the upper and lower members. Three knobs ensured the complete seating of the assembly, so that all the three knobs, master die, and two square blanks would become an assembly (Figs. 1, 2).

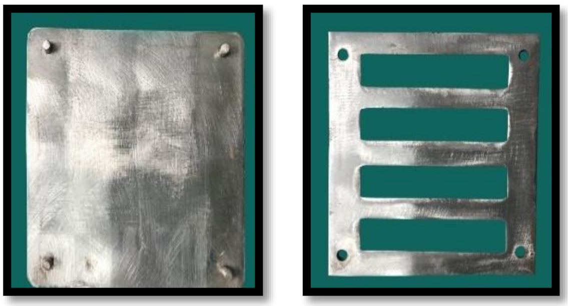

Figure 1. Parts of Metal Die

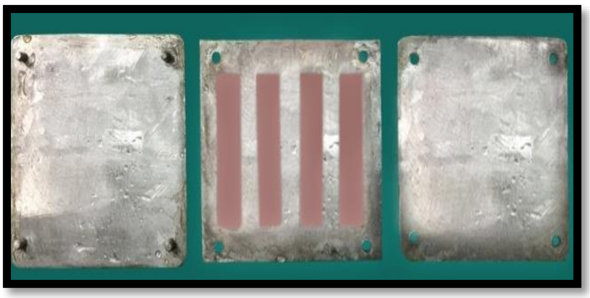

Figure 2. Metal Die Assembly

2. Fabrication of the Specimens

2. 1. Mixing of the Filler (Aluminum Oxide) and PMMA

Aluminum powder with 99.9% purity and the average particle size of 1-10 was selected as the filler. PMMA and the filler particles were weighed in an electronic weighing balance, and accurate volumes of 8% and 13% of the filler were determined based on the following formula:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

The metal filler and PMMA were pre-weighed to ensure the filler concentrations of 8% and 13% based on weight. Initial mixing and blending were performed using a mortar and pestle until obtaining a uniform mix. Mixing continued until no specks, streaks or spots of two different colors were observed, and a mix with uniform color was obtained (Fig. 3). Following that, various concentrations of aluminum oxide were added to the denture base resins in order to place 30 samples per each group. The samples groups in this research were as follows:

Figure 3. Aluminum Oxide Filler Added to Heat-cured Polymer

- Group A1 (control): unmodified, heat-cured denture base resin (DPI);
- Group A2: heat-cured DPI modified with 8% by weight of aluminum oxide powder;
- Group A3: heat-cured DPI modified with 13% by weight of aluminum oxide powder

The material used for the preparation of the specimens was conventional heat polymerized DPI in the powder and liquid forms. The concentrations of 8% and 13% by weight of aluminum oxide powder were weighed using a digital weighing scale and mixed with the polymer of the conventional heat polymerized DPI.

Before mixing the powder, the lower member and master die were assembled. Separation of the media (thin film) was applied on the stainless-steel master die using a brush, and the media was allowed to dry. The monomer and polymer were mixed in all the study group in accordance with the instructions of the manufacturer. The obtained mixture was packed into mold space in the dough stage. Afterwards, the upper member was placed and assembled like a flask. Trial closure was performed, and the extra flash was trimmed using a B.P. knife.

At the next stage, the assembly was placed back on the hydraulic press at the pressure of 1,200 psi and tightened until achieving the metal-to-metal contact of the assembly. The assembly was preserved for bench curing for 30 minutes. The duration of the subsequent curing cycle was 90 minutes at the temperature of 70°C, followed by boiling for 30 minutes. After curing, the assembly was bench-cooled to room temperature and opened to retrieve the cured samples. The process was repeated until fabricating the desired number of samples (Fig. 4).

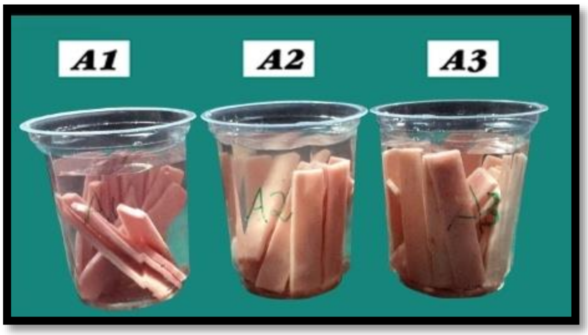

Figure 4. Samples Stored in Distilled Water

2. 2. Criteria for the Selection of the Specimens

In this study, the specimens had to be free of voids, have the diameters of 40*10*3 mm^3 with no irregularity, be crack-free, and have no evident color difference.

2. 3. Retrieval and Storage of the Specimens

The resin samples were retrieved meticulously and inspected for irregularity, and the selected samples were finished and polished. Afterwards, the resin samples were stored in distilled water for seven days, during which the distilled water was changed every day. After seven days, the samples were air-dried before testing in order to determine the flexural strength using a universal testing machine.

3. Testing of the Specimens

All the samples were tested in terms of flexural strength using a universal testing machine (Fig. 5) in order to expose the object (denture) to sudden load based on the following formula:

$S=3PI/2bd^2$

Where S is the flexural strength (MPa), P represents the load at fracture (N), I shows the distance between the supporting wedges (50 mm), b denotes the width of the specimen (mm), and d is the thickness of the specimen (mm).

Figure 5. Sample Being Tested

Results

In this study, each group contained 30 samples of conventional heat polymerized PMMA resin (DPI, Wallace Street, Mumbai, India), which were reinforced with 8% and 13% aluminum oxide powder by weight. After fabrication, the samples were subjected to the universal testing machine to assess the flexural strength (Table I-III).

The flexural strength of the samples was calculated based on the following formula:

Flexural Strength = $S=3PI/2bd^2$

The obtained results were analyzed using one-way analysis of variance (ANOVA). Comparison of groups A1 and A2 (8%) indicated the highest flexural strength (85.94 MPa) in group A2, and the difference in the mean flexural strength was not considered significant. (Diagram 1) Furthermore, a highly significant increase was observed in the values of flexural strength with 13% alumina addition.

Comparison of groups A1 and A3 (13%) showed the highest flexural strength (86.41 MPa) in group A3, and the difference in the mean flexural strength was considered significant. In addition, comparison of groups A2 and A3 indicated the highest flexural strength in group A3, and the difference in the mean flexural strength was not considered significant.

Table I. Mean Flexural Strength (MPa) of Group A1, A2, A3

Groups	Range	Mean	Standard Deviation (SD)
A1(control group)	54.33-82.2	69.60	8.16
A2 (heat-cured DPI modified with 8%)	64.28-107.23	85.94	9.77
A3 (heat-cured DPI modified with 13%)	61.23-108.23	86.41	10.89

Table II. Results of One-way ANOVA regarding Mean Flexural Strength in Study Groups

Groups	Mean	P-value Significant (S)
A1	69.60	
A2	85.94	0.002 (S)
A3	86.41	

One-way ANOVA; *F test; P<0.05 and P<0.01: significant (S);
P<0.001: highly significant (HS)

Table III. Inter-group Comparison of Mean Flexural Strength

Groups	Mean	SD	Difference between Groups		
A1	69.60	8.16	A1-A2	16.34	0.33 (NS)
A2	85.94	9.77	A1-A3	16.81	0.12 (S)
A3	86.41	10.89	A2-A3	0.41	0.56 (NS)

NS: not significant; S: significant

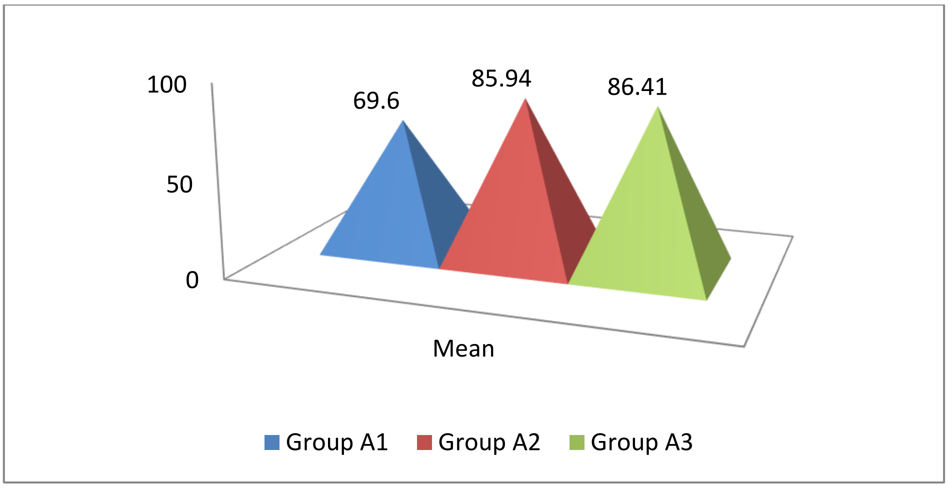

Diagram 1. Mean Flexural Strength in Study Groups

Discussion

Acrylic resins have dominated the denture base world for over five decades. Among various polymeric materials, PMMA has been documented to be the most promising denture base material, which is commercially available. Maxillary dentures are put through bending deformation, with tensile stresses occurring at the labial aspect and lingual to the incisors and onto the polished surfaces. Compressive stresses occur towards the tissue surface, with higher values observed beneath the teeth and on the ridge as compared to those toward the palate.

The present study aimed to enhance the flexural strength of PMMA since it generally affects the durability and longevity of fabricated prosthesis, as well as patient satisfaction with the prosthesis. In the current research, the flexural strength test was used to access the resistance of PMMA denture base resin against the stresses occurring under function. In total, 90 rectangular bar specimens were fabricated for denture base resins, and 30 control specimens of PMMA resin (group A1) were compared with 30 specimens in each experimental group (i.e., PMMA with concentrations of 8% and 13% aluminum oxide by weight in group A and group A3).

Various studies have been documented in the literature pertaining to the reinforcement of PMMA with numerous types of fibers and inserts in an attempt to enhance its mechanical properties. In the present study, aluminum oxide powder was selected as the filler since it not only increases the strength of PMMA, but it also forms thermally-conducting pathways across the insulating polymer. Furthermore, aluminum oxide, which is more commonly known as alumina, has strong ionic interatomic bonds that lead to several advantageous qualities. This element is found in various crystalline phases, all of which revert to the more stable alpha phase at higher temperatures. This phase is of great advantage for various applications.

Alpha-alumina is a strong, stiff oxide with excellent hardness, dielectric properties, refractoriness, and remarkable thermal conductivity, which render it a preferred material for a variety of applications. Additionally, there are other merits to alpha-alumina, including cost-efficiency and ease of manipulation and processing (8). Considering the mentioned advantages of alumina, aluminum oxide was used as the filler in the present study.

Factors such as filler particle size, filler particle distribution in the resin matrix, and filler particle interactions at the interface have major effects on the mechanical properties of resins. Larger filler sizes compared to the matrix particles is associated with higher settling when the powder is mixed with the monomer, which in turn leads to the inferior mechanical properties of the reinforced resin (9). The size of filler particles should be such that it could be finished easily. Therefore, we used the alumina powder with smaller particle sizes (1-10 μm) in the current research. Moreover, the percentage of the applied filler for enhancement should be such that the filler particles could evenly disperse into the resin matrix without disturbing its continuity (1). Proper filler distribution renders resin stronger and more conductive.

In a study by Ellakwa A. E. et al (6). Entitled the “Effect of Aluminum Oxide Addition on the Flexural Strength and Thermal Diffusivity of Heat-polymerized Acrylic Resin”, flexural strength and thermal diffusivity enhanced by adding spherical particles of alumina to acrylic resin. This finding could be attributed to the uniform distribution of the alumina particles within the polymer powder. In another research by Chaijareenont P. et al (10). Entitled the “Effect of Various Amounts of 3-hacryloxypropyltrimethoxysilane on the Flexural Properties and Wear Resistance of Alumina-reinforced PMMA”, use of spherical alumina was recommended to avoid the interlocking effect exerted by elongated shaped fillers. Therefore, the particles with a low aspect ratio (1-10 μm) were selected in the present study, with the additional alumina concentrations of 8% and 13%.

There is controversy regarding the rate of the metal oxides that should be embedded in resin in order to improve its physical and mechanical properties. Several studies have denoted the increased thermal diffusivity of PMMA following the addition of alumina at variable concentrations. With regard to flexural strength, some researchers such as Vojdani M (12) have reported an improvement in the flexural strength of PMMA after the incorporation of alumina at lower concentrations (approximately 2.5 wt%), while Ellakwa A. E. et al (6), Saritha M. K. et al (12), Atla J. et al (13). Have reported no increase at higher concentrations (5, 10, 15, 20, and 25 wt%).

In the present study, comparison of groups A1 (control) and A2 (8%) showed the highest flexural strength (85.94 MPa) in group A2, while the difference in the mean flexural strength of the control and experimental groups was not considered significant. Furthermore, a highly significant increase was observed in the values of flexural strength with the addition of 13% alumina, while an insignificant increase was also observed in the flexural strength with the addition of 5 wt% alumina.

In the current research, comparison of groups A1 (control) and A3 (13%) indicated the highest flexural strength (86.41 MPa) in group A3, while the difference in the mean flexural strengths of the control and experimental groups was not considered significant. On the other hand, comparison of groups A2 and A3 showed the highest flexural strength in group A3, while the difference in the mean flexural strength was not considered significant (Tables I-III).

The results of the present study are consistent with the findings of Saritha (11), who investigated the flexural strength of conventional heat-polymerized denture base resin with the addition of 5%, 10%, and 15% by weight of aluminum oxide powder. The researchers concluded that the flexural strength of conventional heat-cured denture base resin caused no significant increase in the flexural strength of conventional denture resin, while the incorporation of 10% and 15% by weight of aluminum oxide powder to the heat-cured denture base resin significantly increased the flexural strength of the denture base resin, with the highest flexural strength observed in 15% by weight of the incorporation of aluminum oxide powder to the heat-cured denture base resin.

In another research in this regard, Ellakwa (6) Investigated the flexural strength of heat-cured denture base resin with 5%, 10%, 15%, and 20% additional aluminum oxide powder, concluding that flexural strength increased with the addition of aluminum oxide powder to heat-cured denture base resin. Furthermore, Vojdani (12) conducted a research to evaluate the effects of adding 0.5-5% by weight of aluminum oxide powder on the flexural strength, surface hardness, and roughness of conventional heat-polymerized acrylic resin. The concluded result states that reinforcement of the conventional heat-cured acrylic resin with 2.5% by weight, significantly increased the flexural strength and hardness with no adverse effects on the surface roughness.

Clinical Implications

Despite the popularity of material, fractures of PMMA dentures are quite common. The strength of acrylic resin is not enough to maintain the long-term durability of denture acrylics in clinical services. It could be interpreted that aluminum oxide fillers are potential components to be added to denture bases in order to increase the flexural strength. The flexural strength of heat-cured denture base resin increased after the addition of 8% and 13% aluminum oxide particles, depending on the percentage of applied filler particles. Adequate flexural strength of denture base is essential to the longevity of prosthesis.

Limitations of the Study

One of the limitations of the study was that the addition of filler particles led to the discoloration of the resultant resin, which restricted the use of the material on the non-esthetic zones of the denture.

Recommendations for Further Research

1. Further research is required to examine the other physical and mechanical properties of PMMA reinforced with untreated and treated aluminum oxide powder.
2. The effects of aging on these reinforced denture base materials should be further evaluated before the clinical application.

Conclusion

According to the results, the flexural strength of unmodified, heat-cured denture base resin increased with the addition of 8% and 13% aluminum oxide powder. Furthermore, the incorporation of 8% by weight of aluminum oxide powder to heat-cured denture base resin caused no significant increase in the flexural strength of unmodified denture base resin. On the other hand, the incorporation of 13% by weight of aluminum oxide powder to heat-cured denture base resin significantly increased the flexural strength of the denture base resin. Finally, the highest flexural strength was observed with the addition of 13% by weight of aluminum oxide powder to heat-cured denture base resin.

Conflicts of interest

None declared.

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References

1. Anusavice KJ. Phillips' science of dental materials, 11th ed. W.B. St. Louis: Saunders Company; 2003.
2. Eichhold WA, Woelfel JB. Denture base acrylic resins: friend or foe? Compendium. 1990;11(12): 720-725.
3. Brady AP, Lee H, Orlowski JA. Thermal conductivity studies of composite dental restorative materials. J Biomed Mater Res. 1974;8(6): 471-485.
4. Craig RG. Restorative Dental Materials. 11th ed. St Louis: MO, London; Mosby, 2001.

5. Park JY, Kim HY, Kim WC. Comparison of prosthetic models produced by traditional and additive manufacturing methods. J Adv Prosthodont. 2015;7(4): 294-302.
6. Ellakwa AE, Morsy MA, El-Sheikh AM. Effect of aluminum oxide addition on the flexural strength and thermal diffusivity of heat-polymerized acrylic resin. J Prosthodont. 2008;17(6): 439–444.
7. Jagger DC, Harrison A, Jandt KD. An investigation of self-reinforcedPMMR denture base resin using scanning electron andatomic force microscope. Int J Prosthodont. 2000;13(6): 526-531.
8. Jagger DC, Harrison A, Jandt KD. The reinforcement of dentures. J Oral Rehabil. 1999;26 (3): 185-194.
9. Sehajpal SB, Sood VK. Effect of metal fillers on some physical properties of acrylic resin. J Prosthet Dent. 1989;61(6): 746-751.
10. Chaijareenont P, Takahashi H, Nishiyama N , Arksornnukit M. Effect of different amounts of 3-methacryloxypropyltrimethoxysilane on the flexural properties and wear resistance of alumina reinforced PMMA. Dent Mater J. 2012;31(4): 623–628.
11. Saritha MK., Shadakshari S, Nandeeshwar DB, and Tewary S. An in vitro study to investigate the flexural strength of conventional heat polymerized denture base resin with addition of different percentage of aluminium oxide. Asian J Med Clin Sci. 2012;1(2): 80-85.
12. Vojdani M, Bagheri R, Khaledi AA. Effects of aluminum oxide addition on the flexural strength, surface hardness, and roughness of heat-polymerized acrylic resin.JDent Sci.2012;7(3): 238-244.
13. Atla J, Manne P, Gopinadh A, Sampath A, Muvva SB, Kishore K, Sandeep C, and Chittamsetty H. The Effect of Al2O3 Addition on the Thermal Diffusivity of Heat Activated Acrylic Resin. J Clinical Diagn Res. 2013;7(8): 1797-1798.

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