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ORIGINAL RESEARCH

Comparative study of the Compressive Strength of Heat-Cure Acrylic Resin with flexible thermoplastic acrylic

Saeed Abolhasani taraghipour[1], Farnoosh Golmohammadi[2*], Zahra Ghasemi[3]

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Abstract

Backgrounds: Due to the fragility of acrylic in low thicknesses and width of partial prostheses, it is recommended to replace small modifications with fixed prostheses, but sometimes we have to use partial acrylic prostheses. The aim of this study was to examine the compressive strength of heat-cure acrylic with flexible acrylic.

Materials and Methods: In this experimental study ten blocks sized 25 × 2.5 ×10 mm were prepared from each acrylic sample. Universal test machine was used to measure the compressive strength of the samples. Data obtained were analyzed using Wilcoxon test (α = 0.05).

Results: At about mm compression, heat-cure acrylic fractured and the mean compressive strength was 6464.60 ±1288.2279 MPa. The mean force on the flexible acrylic at about 1mm compression was 2830± 323/350 MPa. The difference between the two forces was significant (P = 0.005). The mean compressive strength of flexible acrylic was 5436.60 ± 507.073 MPa. The compressive strength of flexible acrylic was lower than heat-cure acrylic (P = 0.028).

Conclusion: At the same compression rate, the force applied to the flexible acrylic is less than half the force applied to the heat-cure acrylic and in the case of making prostheses, the amount of force on the edentulous ridge at the same bite force is significantly less in dentures with flexible acrylic. Since it is important to introduce necessary transmitted occlusion forces to maintain the continuity of the edentulous ridge, heat cured acrylic is preferred. On the other hand, despite lower compressive strength, flexible acrylic is resistant to fracture and can be successfully used in small modifications of removable partial dentures.

Keywords: Compressive Strength; Acrylic Resins; Denture, Partial, Removable

Introduction

Today, tooth loss is a common problem for societies and a solution to this problem is the use of removable and fixed prostheses. The main base of removable prostheses is acrylic, which should have general characteristics such as biocompatibility, beauty, ease of construction and cleaning. Also, it must have suitable mechanical properties such as hardness, elasticity, high transverse, compressive and impact strength (1).

Corresponding author: Farnoosh Golmohammadi
Department of Prosthetic Dentistry, Faculty of Dentistry, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
Email: Farnoosh.gol@gmail.com

[1]Faculty of Dentistry, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[2]Department of Prosthetic Dentistry, Faculty of Dentistry, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[3]Department of Prosthetic Dentistry, Faculty of Dentistry, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

Over the years, various materials have been used to make denture bases. The most common materials used are polymers. Among polymers, polymethyl methacrylate is widely used due to its aesthetic and mechanical properties (2). Today, flexible acrylics are also used, which are monomer-free and made of thermoplastic nylon. These acrylic materials have proven to be very effective in clinical settings for creating partial acrylic prostheses.

One common issue associated with dental prostheses is the occurrence of fractures, which frequently take place within the oral cavity during functional Clinical evidence suggests that major fractures occur after several years of denture fabrication, and impact fracture can occur due to the sudden dropping of the denture from the patient's hand. Poor fatigue resistance, low tensile strength and impact strength are responsible for denture fractures. Furthermore, fracture of the denture at its midline is the result of compressive fatigue.

The difference in the type of acrylic resin and the different preparation method improves the fracture strength of acrylic resin (3, 4). In partial acrylic prostheses, where there is limited space for tooth replacement, fractures are more common. The fracture resistance of polymer-based prosthesis is the subject of research. Polymethyl methacrylate polymers have a higher degree of compressive strength than other acrylics. polymers that polymerize with visible light were also studied, but contradictory results were obtained from these studies (5, 6).

Polymethyl methacrylate has favorable properties, including ease of use and its low price. However of the main disadvantages of polymethyl methacrylate is the fracture of the resin base of the denture after using it in the mouth, which often occurs in the midline of the upper jaw (7-9) twice as often as lower denture (10). In most cases, fracture in the dentures is more related to problems in the design and manufacture of the prosthesis than the problems of the acrylic resin, such as improper occlusion or poor compatibility of the prosthesis with the underlying tissues (11).

Also, this fracture can be related to the presence of weakening areas such as a deep labial notch (11) or impacts that accidentally hit the denture (12). In addition, it is known that as a result of frequent chewing forces that may be applied to the prosthesis base up to five hundred thousand times a year, the prosthesis base undergoes deformation and ultimately fatigue and fracture (9).

The occurrence of fatigue in the prosthesis occurs faster with the increase in the number of times of bending and the increase in the amount of force, but this phenomenon is significantly related to the shape of the palate and its depth (13, 14). One of the easiest ways to overcome this problem is to increase the thickness of the prosthesis. Of course, with the increase in thickness, other problems such as nausea or reduced retention and stability of teeth and speech problems will arise (11). Today, other methods have been proposed to increase the compressive strength of the prosthesis base, such as the use of high-strength acrylics (15) and the use of reinforcing methods such as metal bases or wires, reinforcing fibers, etc. (16, 17). Although the use of flexible thermoplastic acrylics has shown significant clinical success, it has been investigated in fewer studies. Therefore, in this study, the decision was made to compare the compressive strength of thermoplastic acrylic with conventional methyl methacrylate acrylic.

Materials and Methods

This study investigated the compressive strength of heat-cured acrylic resin with flexible thermoplastic acrylic. A total of 20 samples were examined, each 10 specimens from each type made one group. To prepare samples, metal blocks made of stainless steel with dimensions of $2.5 \times 25 \times 10$ mm were made. These dimensions were chosen based on the approximate size required to replace a tooth in small modifications (18). Metal blocks were muffled in plaster as templates for making heat-cured acrylic and thermoplastic flexible acrylic blocks. According to the manufacturer's instructions, in order to produce heat-cured acrylic resin, acrylic resin powder and liquid (ProBase Hot, Ivoclar Vivadent AG, FL-9494 Schaan / Liechtenstein) were mixed in a glass container, and after reaching the appropriate consistency and removing the metal block inside the plaster, the acrylic resin was poured into the resulting space. Then brass flask was closed and placed under 80 PSI pressure for 2 minutes and after that placed under a pressure of 100 psi for 10 minutes. After placing the brass flask inside the stirrup, it was cooked in a container containing 74°C water for 120 minutes and then 100°C water for more than 60 minutes (19).

In order to produce thermoplastic flexible acrylic, according to the manufacturer's instructions, flexible acrylic granules were injected at 230°C and 5 bar compressor pressure in the space created after removing the metal block in the brass flask (Flexite plus, Felexite company). This denture base material is made of thermoplastic nylon and is free of monomer (Figure 1). After preparing the samples, the additions of each block were removed.

Figure 1. Muffled acrylic blocks. The right side is the flexible acrylic blocks and the left side is the heat-cure blockes

To compare the strength of two types of acrylics, a shear test was initially considered as a pilot test to assess tensile strength. During testing, the heat-cured acrylic samples broke when subjected to a three-point

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bending test. However, the flexible acrylic samples, measuring 25 × 2.5 × 10 mm, disengaged from the supports of the testing machine before any deformation occurred, making it impossible to evaluate their shear strength. Consequently, it was decided to compare the strength of these two acrylic models using compressive strength tests instead.

To measure the compressive strength of the samples, a universal test device (Instron, Zwick/Reoll, 2 wick GmbH, Germany) was used, and the samples were loaded under a vertical force at a speed of 5 mm Per minutes in the 1mm concentration area. In order to check the compressive strength, the samples are bent until they break apart (20). After collecting the strength of the samples, the obtained data were entered into SPSS software version 26 and analyzed using the Wilcoxon test at a significant level of 5%.

Results

Compressive strength is the maximum pressure that a material can withstand before breaking or changing its shape (20). The samples were pressured in the Instron machine. Since the thickness of the samples was 2.5 mm, the machine gradually pressed the samples. (5mm per minutes) The heat-cured acrylic samples were compressed until they fractured, and the force at the time of their fracture was recorded. All the heat-cured acrylic samples broke when the lever of the machine was pressed 1 mm. Of course, this fracture in some samples was slightly less than 1 mm in compression. In the other group, flexible thermoplastic acrylic samples were pressured and the force exerted on the acrylic was recorded at a compression of approximately one millimeter by the Instron device. The amount of compression on flexible acrylic samples resemble the amount of compression that results in the breakage of heat-cure acrylic samples. In this amount of compression, no deformation occurred for flexible acrylic, and the amount of force applied to flexible acrylic in this amount of compression was less than half of the force applied to heat-cure acrylic (2830 versus 6464.6 MPa) and since the samples only found elastic deformation at this compression, the amount of compression until plastic deformation and final crushing of these samples continued. The compression rate of the device increased up to the thickness of the samples which was 2.5 mm, and the flexible acrylic samples reached irreversible deformation. Finally, despite the compression to the final limit of 2.5 mm of acrylic thickness, none of the flexible acrylic samples fractured, but suffered irreversible deformation.

The amount of force applied to acrylic samples at the time of fracture at 1 mm compression and flexible acrylic samples at approximately 1 mm and 2.5 mm compression is shown in the table1.

Table 1. Force acting on heat -cured acrylic and flexible thermoplastic acrylic

The force applied to the heat-cure acrylic at fracture in MPa	The force applied to flexible acrylic equivalent the amount of compression cause fracture of heat-cure acrylic in MPa	The force applied to flexible acrylic in one millimeter of compression in MPa	Force exerted on flexible acrylic at 2.5 mm compression in MPa
8146.060 (fracture at 1 mm)	3200 (force in 1 mm of compression)	3200	5919.500
5500 (fracture at 0.8 mm)	2200 (force in 0.8 mm compression)	2990	5438.200
3600 (fracture at 0.7 mm)	2500 (force at 0.7 mm compression)	3200	5429.14
6500 (fracture at 0.95 mm)	2900 (force at 0.95 mm compression)	3000	5123.480
7000 (fracture in 1 mm)	3000 (force in 1 mm of compression)	3000	5116.0180
6500 (fracture at 0.9 mm)	3200 (force in 0.9 mm compression)	3300	6487.740
7700 (fracture at 0.95 mm)	3000 (force in 0.95 mm compression)	3150	5121.280
7000 (fracture in 1 mm)	3200 (force in 1 mm of compression)	3200	5804.860
5700 (fracture at 0.79 mm)	2600 (force in 0.79 mm compression)	3000	5176.620
7000 (fracture at 0.95 mm)	2700 (force in 0.95 mm compression)	2800	4749.2

In order to compare the obtained data, the amount of force applied to the heat-cured acrylic at the time of fracture was compared with the amount of force applied to the flexible acrylic at the same compression level that caused the heat-cured acrylic to fracture. The results show in table 2.

Table 2. Comparison of the force on heat-cure acrylic at the time of fracture with the force on flexible acrylic in compression equivalent to fracture of heat-cured acrylic.

Compressive strength	Number	Mean± SD (MPa)	Minimum	Maximum	P value
Heat-cure acrylic	10	6464.60±1288.279	3600.00	8146.06	0.005
Flexible thermoplastic acrylic	10	2830.00±323.350	2200.00	3200.00	

Since the data were paired dependent, the Wilcoxon test was used because Investigating the amount of force applied to about one millimeter of flexible acrylic compression was due to the result that heat-cure acrylic fractured in one millimeter of compression.

According to the results in the table 2, the Wilcoxon test is significant (P=0.005) and therefore, at the 95% confidence level, it can be said that there is a significant difference between the force exerted on heat-cure acrylic at the time of fracture and the force exerted on flexible acrylic in compression equivalent to the fracture of heat-cure acrylic. The force on heat-cure acrylic is greater than the force on flexible acrylic in the equivalent compression.

A comparison of the compressive strength of heat-cure acrylic with flexible acrylic was done by comparing the force on heat-cure acrylic at the time of fracture with the force on flexible acrylic at the maximum crushing (2.5 mm) in the next step, the results of which are shown in the table 3.

Table 3. Comparison of compressive strength of heat-cure acrylic with flexible thermoplastic acrylic

Compressive strength	Number	Mean ± SD (MPa)	Minimum	Maximum	P value
Heat-cure acrylic	10	6464.60±1288.279	3600.00	8146.06	0.028
Flexible thermoplastic acrylic	10	5436.60±507.073	4749.20	6487.74	

Since the data were paired dependent, the Wilcoxon test was used. Compressive strength is the maximum pressure that a material can withstand before breaking or changing its shape. In heat-cure acrylic fracture happened and in flexible acrylic crush happened. According to the results in the table3, the Wilcoxon test was significant (P=0.028) and therefore, at the 95% confidence level, it can be expressed that there is a significant difference between the mean compressive strength of heat-cured acrylic and flexible acrylic, and the mean compressive strength of heat-cured acrylic is greater than the mean compressive strength of flexible acrylic.

Discussion

Denture fracture is a common occurrence in prosthetic treatment, but this problem has not been solved yet. Most fractures occur inside the mouth during function. The difference in the type of acrylic resin and different processing technique improves the fracture toughness of acrylic resin (21). Several methods are used to compare the strength of acrylic resins, one of them is measuring the compressive strength.

The results of present study showed that at the same compression level of these two acrylic samples, the force applied to flexible acrylic is less than half of the force applied to heat-cured acrylic. These data can show that in the case of making prosthesis with these two acrylic types, the amount of force on the edentulous ridge in the same amount of mouth closure or the same bite force are significantly different from each other. It is important to introduce occlusion forces in an appropriate amount to maintain the edentulous ridge. Therefore, it can be concluded that flexible prostheses apply bite force to a lesser extent on the underlying edentulous ridge. Given these findings, along with references recommending the necessary transmitted force to preserve the integrity of the edentulous ridge, heat-cured acrylic is preferred. The results of this study are significant and should be taken into account (22, 23).

The mean compressive strength of heat-cure acrylic was higher than the compressive strength of flexible thermoplastic acrylic. One of the important reasons for creating higher compressive strength in heat-cure acrylics can be due to the effect of polymerization conditions of heat-cure acrylics. In previous studies, it has been stated that in heat-cure acrylics, the amount of monomer remaining in the resin and mechanical properties have a close relationship with the polymerization conditions (24-26). For example, Harrison and Huggett (25) stated that long cycles Water bath without end boils makes the amount of residual monomer 3 times higher than when end boils are done. The remaining monomer can be effective on the strength of the final denture due to its plasticizing properties (26, 27). Considering the importance of remaining monomers in the strength of heat-cure acrylics, the difference between heat-cure and flexible acrylic can be explained, because thermoplastic acrylics are made of thermoplastic nylon and are free of monomers.

The effect of powder plasticizer and the amount of residual monomer in acrylic resin has an effect on the strength of acrylic resin(4). In the study of Uzun and Hersek, (28) which compared the fracture strength of heat-cure acrylic resin and injection acrylic resin, it was found that heat-cure acrylic resin has more fracture strength than injection acrylic resin, which may be due to the remaining bubbles during polymerization. Also, polymerization time and cross-link structure can have an effect on the fracture strength of acrylic resin.

In the study of Uzun and Hersek (28) the fracture strength of six types of acrylic resin were investigated, the fracture strength of injected acrylic resin was significantly higher, so the type and method of making acrylic resin plays an important role in fracture strength. Injected acrylic resin has a lower elastic coefficient. This low elastic coefficient increases the fracture strength of injected acrylic resin. Injected acrylic resin contains nylon polycarbonate. This material increases the fracture strength of injected acrylic resin (29). The results of the present study was not in accordance to the study of Uzun and Hersek (28) which can be due to the difference in the type of acrylics investigated in the two studies. In their research, six types of acrylic resins were investigated, and the main focus of the researchers was on the method of making resins. However, it can be stated that apart from the effect of type of materials used to make dentures on the compressive strength, the processing method of preparing acrylic resin is also very important (4, 24-27).

In the study of Ghasemi et al. (30), who investigated the compressive strength of three types of acrylics, stated that heat-cure acrylics have a higher average compressive strength than injected acrylics. But the flexural strength of injected acrylics is much higher than heat-cure acrylics. They stated that the reduction of flexural strength in these samples is not directly related to the amount of monomer remaining in the structure of acrylics. Among other factors that affect the physical properties of acrylics, we can mention the type and molecular weight of the polymer, the amount of plasticizer, the type, size and amount of fillers used in the structure of the polymer. Therefore, according to the points mentioned and the lack of access to information related to the chemical structure of the investigated acrylics, the explanation of the reason for the decrease in the bending strength of the samples requires more investigations. Therefore, the results of the present study showed a similar relationship with the research of Ghasemi et al. (30) Study of Memon et al. (31)also reached the conclusion that the effect of different manufacturing methods has an effect on the mechanical properties of acrylics. They stated that the compressive strength of heat-cure acrylics is higher than acrylics with plasticizers.

Singh et al. (32) noted that if aesthetics are a priority for the patient, flexible partial removable prostheses can be used. However, if aesthetics are not a concern, these dentures should be introduced in later stages of treatment, as they possess weaker mechanical properties compared to heat-cured acrylics.

From an alternative perspective, it is evident that the heat-cured acrylic samples displayed considerable hardness and rigidity, requiring a greater amount of force to induce fracture. In contrast, the thermoplastic flexible acrylic samples exhibited a cushioning effect, allowing them to withstand the same amount of closing force with significantly less resistance.

Perhaps even at maximum compression it still did not fracture and still endured less force than the amount of force in fracture of heat-cured acrylic. According to the definition of compressive strength, it expresses the maximum pressure that a material can withstand without changing its shape (20). The nature of deformation was different in these two types of acrylic. In heat-cured acrylic, the samples fractured, while in flexible acrylic, the samples underwent plastic deformation.

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This can explain the difference in the compressive strength of these two acrylic samples to some extent. Although heat-cured acrylic has higher compressive strength and can withstand more force before fracture, it can withstand less compaction on closure. On the other hand, flexible acrylic did not get perforated even in very thin thicknesses despite the crushing and plastic deformation. Therefore, it can be successfully used in cases where the distance between the jaws is small or in partial acrylic prostheses in small modifications where there is a possibility of breaking or separating the acrylic.

Conclusion

The compressive strength of heat-cured acrylic was much higher than the compressive strength of flexible acrylic. Also, at the same compaction rate, the force applied to the flexible acrylic is less than half the force applied to the heat-cured acrylic. These data show that in the case of making prosthesis with these two acrylic types, the amount of force on the edentulous ridge at the same bite force is significantly less in dentures with flexible acrylic. Since it is important to introduce necessary transmitted occlusion forces to maintain the continuity of the edentulous ridge, heat-cure acrylic is preferred in removable dentures. On the other hand, the results show that flexible acrylic, despite lower compressive strength, even in full thickness compression is resistant to fracture and can be successfully used in small modifications of removable partial dentures.

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