

## Effect of Polypropylene Fiber Addition on the Flexural Strength, Fracture Toughness, and Hardness of Heat-Polymerized Acrylic Resin

Mohammed K Fahmi<sup>1\*</sup> and Mohamed I Ebrahim<sup>2,3</sup>

<sup>1</sup>Department of Restorative Dentistry, Taif University, Taif, Saudi Arabia

<sup>2</sup>Department of Restorative Dentistry, Taif University, Taif, Saudi Arabia

<sup>3</sup>Department of Dental Biomaterial, Al-Azhar University, Cairo, Egypt

\*Corresponding Author: Mohammed K Fahmi, Department of Restorative Dentistry, Taif University, Taif, Saudi Arabia.

Received: February 09, 2017; Published: March 09, 2017

### Abstract

**Purpose:** Polymethyl methacrylate (PMMA) suffers from poor mechanical strength and far from ideal for maintaining the longevity of denture. The purpose of this study was to evaluate the effect of polypropylene fiber powder with concentration 10% by weight of the acrylic resin polymer powder on the flexural strength, fracture toughness, and hardness of heat-polymerized acrylic resin.

**Materials and Methods:** Polypropylene fiber powder with concentration 2% by weight of the acrylic resin polymer powder were incorporated into heat-cure acrylic resin (PMMA) and processed by proportion (2.5:1 Powder/monomer ratio then packing and finally water bath curing for 2 hours at 95°C) to fabricate test specimens of PMMA of dimensions (65 mm length x 10 mm width x 2.5 mm thickness) were used for measuring flexural strength, fracture toughness, and (30 mm length x 10 mm width x 2.5 mm thickness) for measuring surface hardness were prepared according to International Standards Organization (ISO) Specification No.1567. PMMA without additives was prepared as a test control. This types of mechanical tests; flexural strength, fracture toughness and hardness were carried out on the samples. The recorded values of flexural strength in (MPa), fracture toughness in (MPa.m<sup>1/2</sup>), and hardness (VHN) were collected, tabulated and statistically analyzed. One way analysis of variance (ANOVA) and Tukey's tests were used for testing the significance between the means of tested groups which are statistically significant when the P value ≤ 0.05.

**Results:** Addition of polyethylene fiber to PMMA significantly increased the flexural strength, fracture toughness and hardness.

**Conclusion:** These results indicate that polyethylene fiber added to PMMA has a potential as a reliable denture base material with increased flexural strength, fracture toughness, and hardness. According to the results of the present study, the best mechanical properties were achieved by adding polypropylene fiber powder with concentration 2 % by weight on acrylic resin polymer.

**Keywords:** Polypropylene Fiber; Flexural Strength; Heat-Polymerized Acrylic Resin

### Introduction

The most popular material for the construction of complete dentures are acrylic resin [polymethyl methacrylate (PMMA)] it has been for many decades as it has many advantages such as good aesthetics, accurate fit, stability in the oral environment, easy laboratory and clinical manipulation, and inexpensive equipment's [1]. It is the most widely used for fabrication of denture bases; this material is still deficient to achieve the perfect mechanical requirements for dental applications. This problem was attributed mainly to its low fracture resistance and plaque accumulation [2].

Denture base fracture in the mouth occurs through overwork mechanism and over a period of time; so small flexural stresses lead to the formation of microscopic cracks in areas of stress concentration, these cracks fuse to ever growing fissure that weakens the material. Cyclic loading was lead to catastrophic failure that exceeds mechanical capacity of remaining sound portion of the material. As an extra facto denture fracture is also frequently related to faulty design, fabrication and material choice [3].

The other approach is the reinforcement of PMMA denture base resin with various types of fibers which include glass fiber [4,5], sapphire whiskers fiber [6,7], aramid fiber [8], carbon fibers [9,10], nylon fibers [11] and polyethylene fiber [12-14]. However, these fibers windup the homogeneous matrix of acrylic resin due to poor connect between fiber and resin which assuming the mechanical properties. To avoid this problem, surface treatment of fibers have been reported in the literature by many studies [4,13].

In view of above observations, a study was considered to find out how the strength of acrylic resin can be improved by using fiber reinforcement and whether surface treatment affect the impregnation of fiber within the resin matrix. To date, no studies have been reported in the dental literature using surface treated polypropylene fiber for reinforcement in denture base. So the purpose of this study was to investigate the influence of addition of polypropylene fiber on some mechanical properties of heat cured PMMA.

**Material and Method**

An *in vitro* study was conducted to evaluate the effect of polypropylene fiber powder with concentration 2% by weight of the acrylic resin polymer powder on the flexural strength, fracture toughness, and hardness of heat-polymerized acrylic resin.

Heat-cure acrylic resin (PMMA) was used as the control (Acrostone (A), Anglo-Egyptian Company. Hegaz, Cairo, Egypt, Batch No.505/04), ground polypropylene fiber (Sigma-Aldrich Co., St. Louis, MO, USA), which consisted of 18 μm diameter, bundles 2 mm bright, and 0.2 mm tick were soaked in silane for 5 minutes and allowed to air dry completely before they were dipped in a methacrylate monomer for enhanced adhesion of the fibers to resin matrix was also used in this study [2]. Polypropylene fiber was added into heat-cure acrylic resin (PMMA) and processed by proportion (2.5:1 Powder/monomer ratio, conventional packing method and water bath curing for 2 hours at 95°C). 60 bar shapes specimens were prepared to be used in this study. 20 specimens were used for each test [flexural strength (group A), fracture toughness (group B), and hardness (group C)].

**Grouping of the specimens**

Each group was further divided into two subgroups (1 and 2) of 10 specimens each as shown in Table 1.

Groups	Subgroups	Description	No. of Specimens
Group A	Group A1	Heat-cure acrylic resin (PMMA) without additives as control.	10 specimens
	Group A2	PMMA with 2% polypropylene fiber.	10 specimens
Group B	Group B1	PMMA without additives as control.	10 specimens
	Group B2	PMMA with 2% polypropylene fiber	10 specimens
Group C	Group C1	PMMA without additives as control.	10 specimens
	Group C2	PMMA with 2% polypropylene fiber.	10 specimens
Total			60 specimens

**Table 1:** Classification and grouping of the specimens.

### Flexural Strength

Specimens were tested by 3-point bend test on Lloyd universal testing machine (model LRX plus II, Fareham, England) at a cross head speed of 1 mm/min. For the 3 point bend test, a fixture was fabricated with the dimensions (65 mm length x 10 mm width x 2.5 mm thickness) according to International Standards Organization (ISO) Specification No.1567 as shown in table 2.

Two plates were welded at a distance of 15 mm from the center on either side on top of the equipment. A customized “T” shaped stress applicator rod with the dimension of 80 × 20 mm was fabricated, by which stress can be applied in the center of the specimen. The specimen was placed on the rollers which center of the specimen was synchronizing with the center of the distance between the two rollers.

The unit was mounted on the universal testing machine on the lower jaw and the stress applied from upper jaw. A load was applied with “T” shaped rod on the center of the specimen until fracture occurred and peak force (F) values were recorded at this point in Newton [15].

The maximum force (F) necessary to produce fracture of the specimens was recorded in Newton. The flexural strength Q was calculated in (MPa) for all specimens from the “Equation (1)”:

$$Q = \frac{3FI}{2BH^2}$$

“In this formula, “F” is the maximum load or force which is applied to the center of the specimen to fracture it (N); “I” is the distance between the two rests on the surface under the tensile force (mm); “B” is the width (mm) and “H” is the height of the specimen between the surfaces under the tensile and compressive forces (mm)”.

### Fracture Toughness

For fracture toughness testing, specimens were fabricated with the dimensions of (65 mm length x 10 mm width x 2.5 mm thickness) according to International Standards Organization (ISO) Specification No.1567 as shown in table 2. All specimens were stored in distilled water at 37°C for 24 hours then a notch was made in the middle of each specimen on one edge with 2.5 mm lengths using sand paper disk. Fracture toughness were applied on Lloyd universal testing machine (model LRX plus II, Fareham, England) with a cross-head speed of 1 mm/min and load to fracture was recorded. The data were recorded for fracture toughness (K<sub>Ic</sub>) in MPa.m<sup>1/2</sup> according to the “Equation (2)” [16]:

$$K_{Ic} = pc / bw^{1/2} . F (a / w)$$

Where pc is the maximum load (kN) prior to crack advance, b is specimen thickness (cm), w is the width of the specimen (cm), a is crack length (cm) and F is calculated from the following Equation (3):

$$F_{a/w} = \frac{(2 + a / w) (0.886 + a / w - 13.32 a^2 / w^2 + a^3 / w^3 - 5.6 a^4 / w^4)}{(1 - a / w)^{3/2}}$$

**Hardness**

For Hardness testing, specimens were fabricated with the dimensions of 30 mm length x 10 mm width x 2.5 mm thickness according to International Standards Organization (ISO) Specification No.1567 as shown in table 2. Surface hardness was determined by using the microhardness machine [Digital Display Vickers Microhardness Tester (Model HVS-50, Laizhou Huayin Testing Instrument Co., Ltd. China)] which is suitable for polymer material with Vickers diamond indenter and a 20× objective lens. The load applied was 20 gram on the surface of the specimens for 15 sec. five indentations were equally placed over a specimen and not closer than 1 mm to the adjacent indentations or to the margin of the specimens were made on the surface of each specimen. The length of indentations was measured by built in scaled microscope.

Surface microhardness calculation:

Vickers microhardness was obtained using the following Equation (4):

$$VHN = 1.854 L / d^2$$



Where:

VHN: Vickers hardness in Kg/mm<sup>2</sup>.

L: Load in Kg.

d: Length of the diagonals in mm.

The recorded values of flexural strength, fracture toughness, and hardness were collected, tabulated and statistically analyzed. One way analysis of variance (ANOVA) and Tukey’s tests were used for testing the significance between the means of tested groups which are statistically significant when the P value ≤ 0.05.

Test	Master die	Dimensions (ISO specifications 1567)
flexural strength and fracture toughness		65 mm length x 10 mm width x 2.5 mm thickness
Surface hardness		30 mm length x 10 mm width x 2.5 mm thickness

**Table 2:** Showing dimensions and shape of master dies for different tests.

**Results**

**Flexural Strength**

Both Table 3 and Figure 1 show a comparison between mean flexural strength in (MPa) of the tested groups of PMMA. ANOVA test showed statistically significant difference between two groups.

PMMA specimen with 2% polypropylene fiber (group A2) showed significantly highest mean flexural strength than PMMA specimen without any additives (group A1) [control group]. There were significant differences (P < 0.05).

Material	Mean	SD	P-value
PMMA without additives (group A1)	85.54	1.145 <sup>a</sup>	<0.001*
PMMA with 2% polypropylene fiber (group A2)	113.72	1.96 <sup>b</sup>	

**Table 3:** Comparison between mean flexural strength (MPa) of the tested groups of PMMA.

\*: Significant at P ≤ 0.05, Means with different letters are statistically significantly different according to Tukey’s test

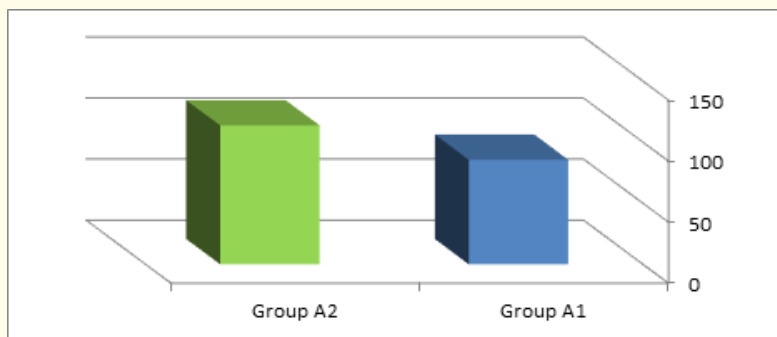


Figure 1: Bar chart of mean flexural strength (MPa) of the tested groups of PMMA.

### Fracture Toughness

The data showed there was significant improvement in the tested groups which were reinforced with 2% polypropylene fiber (Table 4 and Figure 2).

There was significant increase in the fracture toughness for group reinforced with 2% polypropylene fiber when compared with control group.

Material	Mean	SD	P-value
PMMA without additives (group B1)	2.30	0.158 <sup>a</sup>	<0.001*
PMMA with 2% polypropylene fiber (group B2)	3.84	0.15 <sup>b</sup>	

Table 4: Comparison between mean fracture toughness (MPa.m<sup>1/2</sup>) of the tested groups of PMMA.

\*: Significant at  $P \leq 0.05$ , Means with different letters are statistically significantly different according to Tukey's test

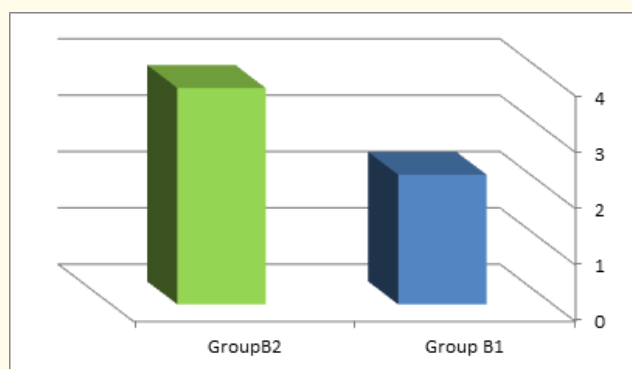


Figure 2: Bar chart of mean fracture toughness (MPa.m<sup>1/2</sup>) of the tested groups of PMMA.

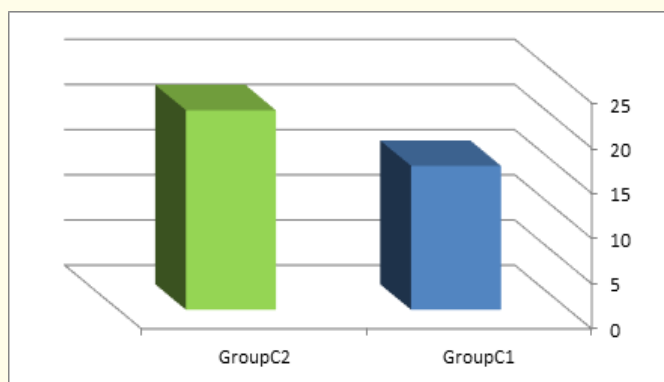
**Hardness**

Both Table 5 and Figure 3 show the mean hardness of tested groups. All specimens showed hardness mean values higher than that control group. PMMA specimen with 2% polypropylene fiber (group C2) showed significantly highest mean hardness than PMMA without additives.

Material	Mean	SD	P-value
PMMA without additives (group C1)	15.92	0.96 <sup>a</sup>	<0.001*
PMMA with 2% polypropylene fiber (group C2)	22.07	1.05 <sup>b</sup>	

**Table 5:** Comparison between mean hardness (VHN) of the tested groups of PMMA.

\*: Significant at  $P \leq 0.05$ , Means with different letters are statistically significantly different according to Tukey's test



**Figure 3:** Bar chart of mean hardness (VHN) of the tested groups of PMMA.

**Discussion**

Improvement mechanical properties of PMMA, in particular, the flexural strength, fracture toughness, and hardness, through incorporating of polypropylene fiber. Generally there are different ways to improve the mechanical properties of PMMA: replacing PMMA with an alternative material; chemically modifying it; and reinforcing the PMMA with other materials [3].

The properties of polypropylene fiber have natural color, good mechanical properties and provided good surface finish and polish. Because of its excellent biocompatibility it has been used in general surgery for closure of abdominal wounds and in oral and maxillofacial surgery for reconstruction of orbital floor, where there are multiple fragment fractures [17]. Composite Manufacturers in American suggests polypropylene as one of the reinforcement material for composite resins so polypropylene fibers were also used in this study for reinforcement in PMMA.

Another property of polypropylene fibers is hydrophobic in nature and has low surface energy so their compatibility with PMMA is poor. If the fiber untreated were acts as inclusion bodies in the acrylic resin mixture and instead of strengthening actually weaken the resin by breaking up the homogenous matrix [4]. The adhesion improved between resin and the fibers by surface modification as silane treatment of polypropylene fibers [18].

Polypropylene fiber incorporation above 3% by weight will affect the flow of the dough and beyond 4% by weight need to be wetted by large volume of monomer during mixing and may produce dry friable dough [12]. So using a standard 2% by weight of each type of fiber was added to each specimen in this study.

Fractures in denture base are a common clinical problem. Flexural strength of resin was measured in this study due to it is considered the primary mode of clinical failure [19]. Fatigue failure does not require strong biting forces as relatively small stresses caused by mastication over a period of time can eventually lead to the formation of a small crack, which propagates through the denture and results in a fracture.

The maximal biting forces of a patient can reach up to 700 N, but these values are reduced (100 - 150 N) [20] with the removal of dentures. Fractures of denture are important due to stress concentration and increased flexing [21]. The fracture toughness seems to be appropriate measurement to demonstrate the effects of resin modifications [22].

The polymerized resin has been found to be sensitive in surface hardness due to residual monomer content in the resin material. Moreover, hardness measurement have been successfully used as an indirect method of evaluating polymerization depth of resin-based composite materials [23] and the degree of conversion of conventional heat polymerizing and self-curing acrylic resins. In addition, hardness has been used to prophesy the wear resistance of dental materials [24].

The results of the present study show increase in flexural strength, fracture toughness, and hardness when addition of polypropylene fiber with concentration 2% by weight. This improvement in mechanical properties could be attributed to the presence of reinforced fibers which carry the load along their length to provide strength and stiffness to the specimen in one direction, resulting in higher absorption of energy compared with un-reinforced specimens [25].

There was significant improvement in flexural strength, fracture toughness, and hardness after surface treatment of polypropylene fiber which may be attributed to the effect of silane coupling agent, which chemically bonds inorganic polypropylene fiber to the organic resin matrix and may make the mixture more homogenous resulting in strong PMMA resin [26].

### Conclusion

On the basis of this study, we can conclude that:

Addition of polypropylene fiber on acrylic resin with concentration 2% by weight polymer were increase in flexural strength, fracture toughness, and hardness of denture base.

### Bibliography

1. Nejatian T., *et al.* "Reinforcement of Denture Base Resin". *Advances in Science and Technology* 49 (2006): 124-129.
2. John J., *et al.* "Flexural Strength of Heat-Polymerized Polymethyl Methacrylate Denture Resin Reinforced with Glass, Aramid, or Nylon Fibers". *Journal of Prosthetic Dentistry* 86.4 (2001): 424-427.
3. Kim S and Watts D. "The effect of reinforcement with woven E-glass fibers on the impact strength of complete dentures fabricated with high-impact acrylic resin". *Journal of Prosthetic Dentistry* 91.3 (2004): 274-280.
4. Solnit G. "The effect of methyl methacrylate reinforcement with silane-treated and untreated glass fibers". *Journal of Prosthetic Dentistry* 66.3 (1991): 310-314.
5. Vallittu P. "Glass fiber reinforcement in repaired acrylic resin removable dentures: preliminary results of a clinical study". *Quintessence International* 28.1 (1997): 39-44.

6. Berrong J, *et al.* "Fracture resistance of Kevlar-reinforced poly(methyl methacrylate) resin: a preliminary study". *International Journal of Prosthodontics* 3.4 (1990): 391-395.
7. Goldberg A and Burstone C. "The use of continuous fiber reinforcement in dentistry". *Dental Materials Journal* 8.3 (1992): 197-202.
8. Vallittu P, *et al.* "Acrylic resin-fiber composite-Part I: The effect of fiber concentration on fracture resistance". *Journal of Prosthetic Dentistry* 71.6 (1994): 607-612.
9. Boer J, *et al.* "The effect of carbon fiber orientation on the fatigue resistance and bending properties of two denture resins". *Journal of Prosthetic Dentistry* 51.1 (1984): 119-121.
10. Vallittu P, *et al.* "Impact strength of denture polymethyl methacrylate reinforced with continuous glass fibers or metal wire". *Acta Odontologica Scandinavica* 53.6 (1995): 392-396.
11. Matthews E and Smith D. "Nylon as a denture base material". *British Dental Journal* 98 (1955): 231-237.
12. Gutteridge D. "The effect of including ultra-high-modulus polyethylene fiber on the impact strength of acrylic resin". *British Dental Journal* 164.6 (1988): 177-180.
13. Gutteridge D. "Reinforcement of poly (methyl methacrylate) with ultra-high modulus polyethylene fibers". *Journal of Dentistry* 20.1 (1992): 50-54.
14. Ladizesky N, *et al.* "Acrylic resins reinforced with woven highly drawn linear polyethylene fibers. 3. Mechanical properties and further aspects of denture construction". *Australian Dental Journal* 38.1 (1993): 28-38.
15. Dagar S, *et al.* "An in Vitro Evaluation of Flexural Strength of Direct and Indirect Provisionalization Materials". *Journal of Indian Prosthodontic Society* 5.3 (2001):132-35.
16. Yilmaz, C and Korkmaz T. "The Reinforcement Effect of Nano and Microfillers on Fracture Toughness of Two Provisional Resin Materials". *Materials and Design* 28 (2007): 2063-2070.
17. Paula E, *et al.* "Tissue reactions of polypropylene mesh used in maxillofacial trauma". *Brazilian Dental Journal* 12.2 (2001): 121-125.
18. Braden M, *et al.* "Denture base poly(methyl methacrylate) reinforced with ultrathin modulus polyethylene fibers". *British Dental Journal* 164.4 (1988): 109-113.
19. Chitchumnong P, *et al.* "Comparison of Three- and Four-Point Flexural Strength Testing of Denture-Base Polymers". *Dental Materials Journal* 5.1 (1989): 2-5.
20. Narva K, *et al.* "Flexural Fatigue of Denture Base Polymer with Fiber-Reinforced Composite Reinforcement". *Composites Part A Applied Science and Manufacturing* 36.9 (2005): 1275-1281.
21. Franklin P, *et al.* "Reinforcement of Poly (Methyl Methacrylate) Denture Base with Glass Flake". *Dental Materials Journal* 21.4 (2005): 365-370.
22. Zappini G, *et al.* "Comparison of Fracture Tests of Denture Base Materials". *Journal of Prosthetic Dentistry* 90.6 (2003): 578-585.
23. Dunn W and Bush A. "A Comparison of Polymerization by Light-Emitting Diode and Halogen-Based Light-Curing Units". *Journal of the American Dental Association* 133.3 (2002): 335-341.
24. Lee S, *et al.* "Influence of Polymerization Conditions on Monomer Elution and Microhardness of Auto-polymerized Polymethyl Methacrylate Resin". *European Journal of Oral Sciences* 110.2 (2002): 179-183.



25. Tushar Krishnarao T, *et al.* "Effect of fiber reinforcement on impact strength of heat polymerized polymethyl methacrylate denture base resin: in vitro study and SEM analysis". *Journal of Advanced Prosthodontics* 4.1 (2012): 30-36.
26. Kanie T, *et al.* "Flexural Properties and Impact Strength of Denture Base Polymer Reinforced with Woven Glass Fibers". *Dental Materials Journal* 16.2 (2002): 150-158.

**Volume 8 Issue 3 March 2017**

**© All rights reserved by Mohammed K Fahmi and Mohamed I Ebrahim.**