Journal of Techniques, ISSN: 2708-8383, Vol. 5, No. 3, 2023, Pages 218-224
https://doi.org/10.51173/jt.v5i3.1740

JOURNAL OF TECHNIQUES

Journal homepage: http://journal.mtu.edu.iq

RESEARCH ARTICLE - MEDICAL TECHNIQUES

The Effect of Recycled CAD/CAM PEEK Fibers on the Transverse Strength of Repaired Acrylic Resin

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Article Info.

Article history:

Received
25 June 2023

Accepted
30 July 2023

Publishing
30 September 2023

Abstract

One of the significant advantages of Polyether ether ketone (PEEK) is its ability to bond composite materials. This makes it a versatile material that can be used in a range of dental applications, including as a framework for fixed or removable dental prostheses. The aim of this study is to evaluate the transverse strength of heat-cured acrylic resin after reinforcing repaired material with recycled PEEK fibers obtained from a CAD/CAM machine. After milling, PEEK fibers were collected from the CAM machine. The size of the PEEK fibers was measured by utilizing a Scanning Electron Microscope (SEM); with the particle grit size being 200 µm. Thirty specimens were used and divided into three groups of heat-cured acrylic resins was evaluated. All specimens have been stored at 37°C prior to fracture, and specimens have been then repaired after fracture with an auto-polymerizing acrylic resin using Ivomet. Group A of heat-cured specimens was used as a (control group) and repaired with no additive to the self-cured acrylic repair materials. While group B has been repaired by self-cured acrylic reinforced with of 1%wt. PEEK fibers, group C has been repaired by self-cured acrylic reinforced with the addition of 2%wt. PEEK fiber. There is a difference between groups A and C; however, there is a significant difference at 0.05 when comparing with groups B and C. When compared to (1%wt. PEEK-fiber) and the control group, adding (2%wt. PEEK-fiber) improves the transverse strength of the repaired heat-cured acrylic resins.

Publisher: Middle Technical University

Keywords: Acrylic Resin; Denture Repair; PEEK Fibers Reinforcement; Transverse Strength; Dental Material.

1. Introduction

In terms of a green environment, the management of biomedical and dental wastes has recently emerged as the primary concern. Numerous studies have recommended recycling or reusing some dental material [1]. However, the majority just possessed a basic understanding. Relating to recycling methods and proper disposal of biodegradable or dental materials that cannot be degraded. Modern practice in both labs. and clinical offices has adopted computer-aided designs as well as manufacturing of production processes (CAD-CAM) over the past 20 years [2, 3]. The high-performance thermoplastic polymer is known as Polyether ether ketone (PEEK) with an aromatic ring and semi-crystalline linear chain structure which are joined bifunctional groups of ether and ketone [4]. It is heat and chemical resistant, has appealing mechanical qualities, strong dimensional stability, is biocompatible, with minimal elastic modulus comparable to human bones [5]. The difficulty and high expense of manufacturing PEEK as a biomaterial are its fundamental disadvantages [6].

The patient has been burdened with a high cost due to the large portions that remain after cutting, even if modern machines have improved cutting precision. These components take the shape of powders, fibers, and unused patches. However, this emphasizes the necessity of recycling the CAM-PEEK waste patches or leftovers [7]. Although polymethl methacrylate (PMMA) is the best base material in terms of aesthetics and adequate stability in the oral environment, its poor mechanical qualities are a significant drawback that restricts its use. Different fillers have been suggested to enhance the mechanical properties. Despite its drawbacks, auto-polymerizing acrylic resin continues to be the most commonly used substance for the repair of dentures [8]. The strength of the repaired acrylic resin might vary depending on a number of factors. For instance, the repair surface's shape is supposedly best provided by a rounded surface. The durability of the repair joint and the strength of the restored resin could be improved by pre-treating the repair surfaces with methyl methacrylate monomer. Using the high impact materials or fibers reinforcement must be taken into consideration in situations that have a history of prior fractures or where fractures are more probably, for example, when complete upper dentures oppose lower natural dentitions [8]. This study was aimed to investigate the impact of addition recycled CAD/CAM PEEK fibers at 1% wt. and 2%wt. on the transverse strength of repaired heat-cured acrylic denture base material.

2. Materials and Methods

2.1. Silicon mold preparation

Nomenclature & Symbols			
PMMA	Poly Methyl Methacrylate	KV	Kilovolt
SEM	Scanning Electron Microscope	fig	Figure
PEEK	Polyether Ether Ketone	˚C	Degree centigrade
ml	Milliliter	mm	Millimeter
min	Minute	µm	Micrometer
gm.	Gram	ANOVA	Analysis of variance
rpm	Revolution per Minute	LSD	Least significant differences
hrs.	Hours	%	Percentage

A silicon mold was prepared by mixing the base and catalyst silicone materials (Sense, Germany). The silicone was poured over a metal bar with dimensions of (64 mm ×10 mm ×3.3 mm) depth, width, and length, as illustrated in Fig. 1. These parameters are defined by the international standards organization ISO 20795-1 (2013) [9]. The base plating wax was melted and then poured into the silicon mold in increments, utilizing the drop-by-drop technique of the Lacron carving instrument used to create the study sample.

Fig. 1. Silicone mould for samples preparation

2.2. Investing procedure

The thirty wax pattern specimens, which were obtained from the silicone mold, were packed, cured, finished, and polished according to the instructions provided by the manufacturer.

2.3. Samples grouping

This study utilized a total of 30 specimens, which were divided into three groups, each containing 10 specimens.

- Group A: 10 PMMA specimens without PEEK fiber addition (Control group).
- Group B: 10 PMMA Specimens with the addition of 1% wt. PEEK fiber.
- Group C: 10 PMMA Specimens with the addition of 2% wt. PEEK fiber.

2.4. Recycled CAD/CAM PEEK fibers

The CAD-CAM fabrication process was used to collect the research PEEK powder from a decomposed PEEK blank (PEEK-Juvora TM). After dry milling and manual grinding, Fig. 2 ISO standard sieves of 3310-1, (2016) [10]. No. 40 ranging from (425–400 µm), no. 60 (250–242µ m), no. 70 (200–212 µm) and no. 100 (150–140 µm), were used to obtain fine particle grit sizes of PEEK [11, 12]. PEEK fiber grit sizes ranged from 200 µm to 212µ m under sieves. A magnet was used to remove any metal particles that may have been integrated into the cutting bur during the sifting process.

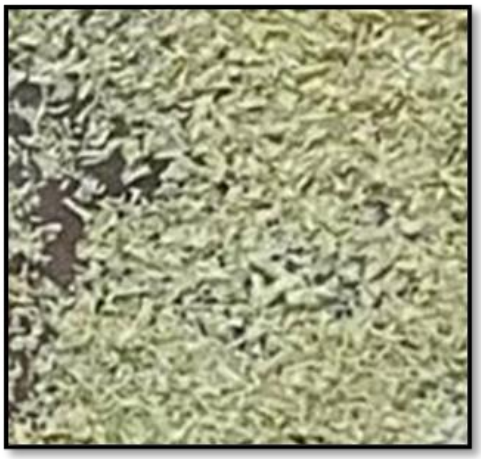

Fig. 2. PEEK waste fibers collection

To evaluate the PEEK fiber particle size, photographs were obtained using a Scanning Electron Microscope (Czech Republic, Netherlands), ser. no. (9921623) at a magnification of 100x and an accelerating voltage of 30 KV. Microscopic analysis of the PEEK fibers revealed that they have an irregular shape, and their surfaces have morphological diameters ranging from (200-212 μm), as shown in Fig. 3.

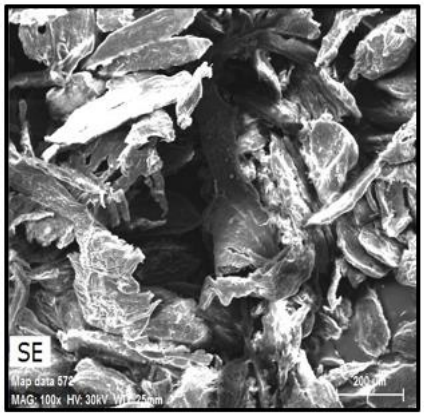

Fig. 3. PEEK fibers under SEM (MAG. 100x)

2.5. PMMA-PEEK repair material prepasration

The self-cured acrylic resin repaired material (Provinice, Shofu In., Japan) was prepared by adding the fibers PEEK at 1%wt. and 2%wt. to the self-curing acrylic resin powder after being pre weighed on the analytical balance (Mettler, Delta Range®, England) as shown in Fig. 4.

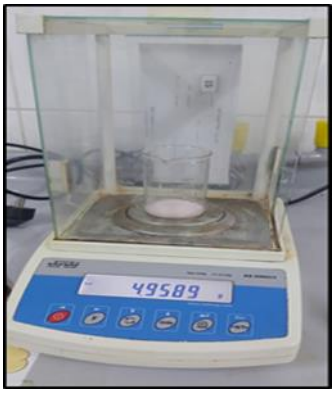

Fig. 4. Sensitive balance device

To get a uniform and even distribution of PEEK fibers in a resin polymer powder, a magnetic stirrer machine (IKA® RW20 digital, Stauffen, Germany) was employed at 450 rpm for 30 minutes for to mix the pre-weighted PEEK fibers with the resin polymer powder according to each group's percent by weight [13], as demonstrated in Table 1, and Fig. 5.

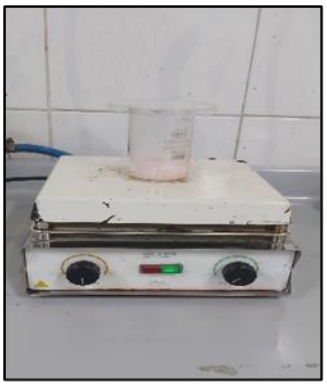

Fig. 5. Magnetic stirrer device

2.6. Repair Procedure

The repair procedure for the acrylic resin samples involved several steps. Initially, the samples were cleaned using ultrasonic waves with distilled water and left to air dry for 10 seconds[14]. The samples were then placed into a silicon mold filled with stone to create a repair index and numbered on the ends to facilitate realignment. The repair samples were cut in half with a band saw, and the joint surface contours were prepared for testing using a tungsten carbide resin acrylic bur to create a round joint. A box measuring 5 × 5 × 2 mm was cut in both joint surfaces of 30 specimens to accommodate the fibers, as shown in Fig. 6, [8]. The joint surfaces were then rounded and smoothed using pumice on a lathe. The

space between the edges to be repaired when placed in the repair indices was 3.0 mm for all samples. To ensure proper alignment during repair, a separating medium was applied to the walls of the repair indices, and sticky wax was placed on the ends of the sample and the index. The repairing specimens were divided into three groups of 10 samples each, as shown in Table 1. The first group was repaired without adding PEEK fiber and served as the control group, while the second and third groups were repaired by adding 1%wt. and 2%wt. PEEK fiber, respectively, to the polymer powder before mixing with acrylic monomer. The repair procedure started by wetting the prepared sample surfaces with a self-cure acrylic monomer, followed by the prepared self-cured acrylic resin powder reinforced with PEEK fiber. The powder and liquid were mixed together according to the manufacturer's recommendations (dispense 0.5 ml of liquid into a mixing cup, then add 1g of powder) within 15 seconds of working time. In this study, 2.5 ml of monomer was mixed with 5g of powder, as mentioned in Table 1. The mix was then allowed to overfill the space to compensate for polymerization shrinkage. The sample was cured using Ivomet for 15 minutes at 37°C and pressure of 301b/Inch2. After curing, the specimens were finished and polished, and then kept in an incubator and stored in distilled water at 37°C [15].

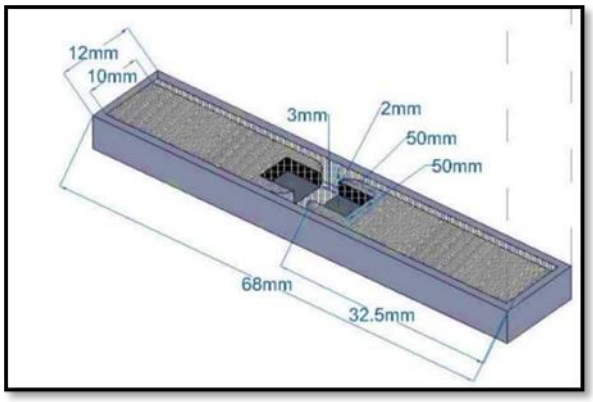

Fig. 6. Diagram illustration the repair joint in the box

Table 1. The composition of Polymethylmethacrylate/Polyether ether ketone (PMMA-PEEK) repair materials for the experimental groups [1]

Groups	Self- cure acrylic resin repair (4.9-5 wt. %)	PEEK-Fibers (0-2 wt. %)	Self-cure acrylic monomer (ml)
(A) Control	5 (g)	0 %	2.5ml
(B)	4.95 (g)	(1% wt.)	2.5ml
(C)	4.9 (g)	(2% wt.)	2.5ml

2.7. Transverse strength test

By using the digital caliper device, the midpoint of all (30) prepared specimens was measured and marked. To assess the transverse strength, a universal testing machine has been used see Fig. 7. The loading wedge was used to set the device, and a pair of adjustable supporting wedges were put 50 mm apart. In the specimen's center, force is employed with a crosshead speed of 5 mm/min. and a load cell of 500 N. The uniformly increasing force was used till the specimens fractured. The value was calculated using the formula below: $S = 3PL/2bd5$ (N/mm^2) S = transverse strength P = maximum force applied to specimens (N) L= measurement of space between supporting rollers b = width of specimen (mm), d = depth of specimen (mm), according to ISO 20795–1:2013 [9].

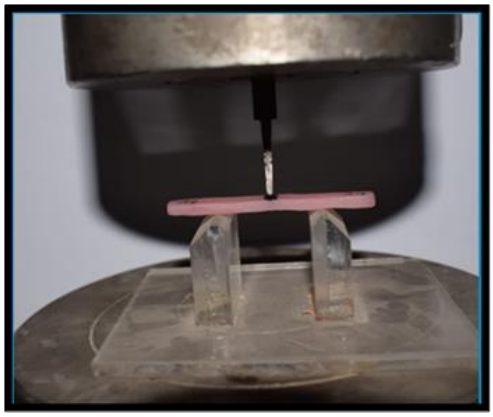

Fig. 7. Transverse strength testing instrument with repaired sample

3. Results

The present study's data were analyzed using one-way ANOVA and LSD tests were utilized to determine the means, which revealed statistically significant differences in Transverse strength groups. The significance level was set at 0.05. The descriptive statistics for the transverse strength test are presented in Table 2 and Fig. 8. The group with highest mean value was recorded in group C, (41.7429 ± 5.01233), followed by group A (34.6000 ± 7.92148), while group B had the lowest mean value (31.9357 ± 5.26145).

Table 2. Descriptive statistics for transverse strength (N/mm^2) for all tested groups

Groups	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
PMMA (control)	10	34.6000	7.92148	2.99404	27.2739	41.9261	20.59	45.84
PMMA+PEEK 1%	10	31.9357	5.26145	1.98864	27.0697	36.8017	21.57	37.75
PMMA+PEEK 2%	10	41.7429	5.01233	1.89448	37.1072	46.3785	34.81	50.50
Total	30							

Furthermore, Table 3. presented a one-way analysis of variance (ANOVA) for the transverse strength of various groups. There was a statistically significant difference between the mean strengths of the three groups.as determined by a one-way ANOVA test.

Table 3. One-way ANOVA test for transverse strength between and within all groups

Groups	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	360.031	2	180.015	4.673	.023
Within Groups	693.337	18	38.519		
Total	1053.368	20			

* Mean difference significant at 0.05.

In Table 4 the LSD analysis showed that there is a significant difference in transverse strength between the different groups at a significance level of 0.05. Specifically, the addition of PEEK fibers at a concentration of 2%wt. resulted in a significantly higher transverse strength compared to samples without PEEK fibers or with 1%wt. PEEK fibers. The mean difference between the PMMA group and the PMMA+2%wt. PEEK group was 7.14286, and the mean difference between the PMMA+1%wt. PEEK group and the PMMA+2%wt. PEEK group was 9.80714, both of which were significant at the 0.05 level.

Table 4. LSD analysis for transverse strength of all groups

(I) Grouping		Mean Difference (I-J)	Sig.
PMMA (control)	PMMA+PEEK 1%	2.66429	.432
	PMMA+PEEK 2%	7.14286*	.045
PMMA+PEEK 1%	PMMA	2.66429	.432
	PMMA+PEEK 2%	9.80714*	.008
PMMA+PEEK 2%	PMMA	7.14286*	.045
	PMMA+PEEK 1%	9.80714*	.008

*The mean difference is significant at the 0.05 level.

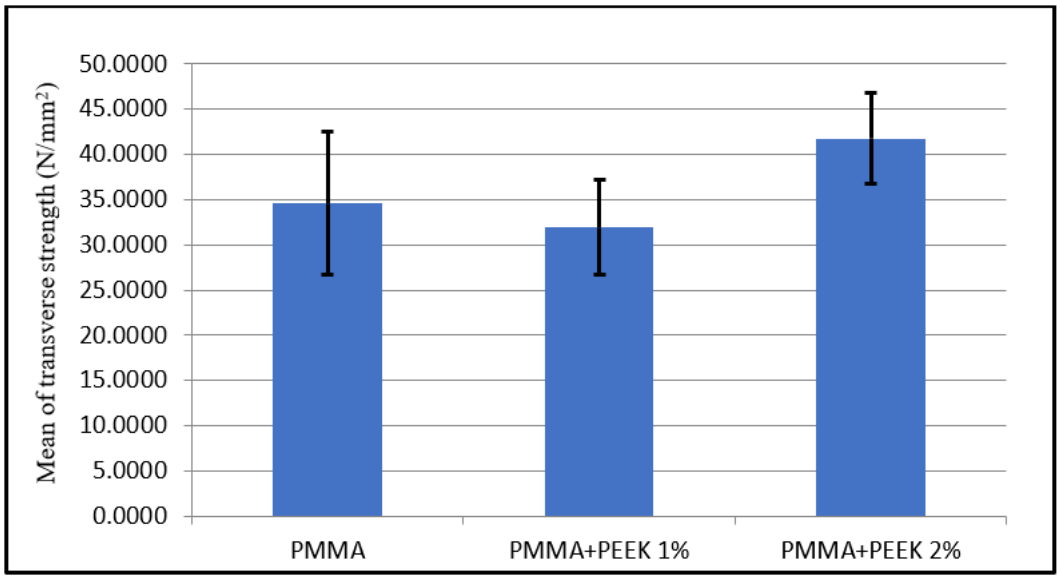

Fig. 8. A bar graph showing the mean distribution of transverse strength (N/mm^2) in several categories

4. Discussion

PEEK (Polyether ether ketone) is currently used in dentistry for the fabrication of clasps and removable dental prostheses. PEEK is a biocompatible material that has been shown to have excellent mechanical properties, including high strength and resistance to wear, fatigue,

and creep. These properties make it an attractive material for use in dental applications, particularly for removable prostheses such as dentures and partial dentures [16].

The transverse strength is a measure of a material's rigidity and resistance to fracture when subjected to bending or flexing forces. In dentistry, the transverse strength of a material is an important consideration, as removable dental prostheses such as dentures and partial dentures are subjected to bending and flexing forces due to the movement of the jaw during biting and chewing [17]. This study investigated the effect of adding PEEK fibers in various wt. % proportions and in chopped form with around joint on transverse strengths of repaired heat cured acrylic resin dentures base materials. The reason for choosing the rounded joint is that it is one of the strongest joint profiles and is easily performed. Distribution and orientation of fibers is important. Uniformly and continuous distribution of fibers gives variable strengthening characteristics to the matrix, The impact of fiber reinforcement depends upon several variables, such as fiber length, type, form (continuous or chopped), arrangements (oriented or random) and the bond of fiber-matrix [8].

In addition, Salim stated that PEEK waste fibers recycling from CAD-CAM productions and reusing it as dental filler at 1%wt. and 2% wt. enhanced the mechanical properties of PMMA [1]. The existence of the box in this study aimed to accommodate the fibers, which showed non-significant differences in the rupture modulus between control samples (group A) mean value, which was (34.600±7.921 N/mm^2) in comparison with the repaired specimens mean values (group B) with the addition of 1%wt. PEEK fibers was (31.9357±5.261 N/mm^2) & showed a significant differences in the rupture modulus between control samples (group A) mean value, which was (34.600±7.921 N/mm^2) in comparison with the repaired specimens mean values (group C) with the addition of 2%wt. PEEK fibers (41.7429 ± 5.01233 N/mm^2). Studies by Gokul et al. and Sri, they found that the addition of E-glass fibers to heat-polymerized acrylic resin can lead to an improvement in transverse strength. Silica dioxide (SiO_2) makes up the majority of E-glass fibers, which is a stiff and strong material that can help to increase the density and strength of the glass fiber structure. The addition of E-glass fibers to the heat-polymerized acrylic resin can help to transfer the load from the resin to the glass fibers, which can improve the overall strength and durability of the denture base [18, 19]. The increased transverse strength of the denture base can help to ensure that it can withstand the bending and flexing forces that it is subjected to during normal use [18, 19].The study done by Jaikumar et al. they indicated that the highest transverse strength values were found in PMMA reinforced with glass fibers followed by PMMA reinforced with butadiene styrene, while the conventional denture base polymers had the least strength. [20]. It is believed that the presence of glass fibers is the primary reason for the increased transverse strength. The glass fibers can prevent the propagation of a crack when stresses are applied, thereby reducing the likelihood of fracture in patients with dense occlusal loads or when the denture base resin is exposed to excessive forces [20].

5. Conclusions

- The addition of 2% wt. recycled PEEK fiber could be an efficient method for improving transverse strength of a repaired PMMA.
- The box involved in the repair joints produced significant increased transvers strength.

Acknowledgment

We would like to thank Dr. Nihad AlFuraiji for her assistance in completing this research.

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