European Journal of Clinical Pharmacy

Print ISSN: 2385-409X **Online ISSN**: 3105-0409

Website: https://farmclin.com/

Original Research Article

Estimation of Fracture Resistance, Impact Strength and Surface Roughness on Kevlar Fiber Reinforced Polymethyl Methacrylate Resin: An In Vitro Study

Article History:

Name of Author:

Dr Jagruti Sudarshan Somani[1], ·Dr Ajay Gaikwad[2], Dr Pronob Kumar Sanyal [3]

Affiliation: *[1]PG Student, Dept of Prosthodontic and Crown and Bridge, School of Dental Sciences, Krishna Vishwa Vidyapeeth (Deemed to be University), Karad – 415539, Maharashtra, India*

[2]Professor, Department of Prosthodontics and Crown and Bridge, School of Dental Sciences, Krishna Vishwa Vidyapeeth (Deemed to be University), Karad 415539, Maharashtra, India.

[3]Professor, Department of Prosthodontics and Crown and Bridge, School of Dental Sciences, Krishna Vishwa Vidyapeeth (Deemed to be University), Karad 415539, Maharashtra, India.

Corresponding Author:

Dr Jagruti Sudarshan Somani

Received: 11-11-2025

Revised: 19-11-2025

Accepted: 12-12-2025

Published: 31-12-2025

Abstract: To estimate the fracture resistance, impact strength and surface roughness on Kevlar fiber reinforced PMMA at different concentrations (2%, 3% & 5%) (w/w), both with and without silane surface treatment. Settings & Design: An invitro study design. ***Materials & Methods***: The study included one hundred eighty-nine samples (n=189) in total. Balanced experimental approach with equal group sampling (n=63) was done among Group A (Fracture resistance), Group B (Impact Strength) & Group C (Surface roughness) that were divided into control group with unreinforced PMMA (n=9) and six experimental groups (n=9) with Kevlar-reinforced PMMA at various concentrations (2%, 3% & 5%). Experimental groups were equally distributed into three untreated subgroups and three treated subgroups with silane coupling agent; Subgroup 1-2%w/w; Subgroup 2- 3%w/w & Subgroup 3- 5%w/w. Conventional heat-polymerization protocols were duly followed & mechanical testing using a universal testing machine for fracture resistance, Izod impact tester for impact strength, and a surface profilometer for surface roughness was done. Statistical Analysis Used: Post Hoc Tukey's & One Way ANOVA was applied for comparisons between groups and subgroups. ***Results:*** Experimental group significantly improved both fracture and impact strength compared to control group. Among all groups, subgroup 3 (5% silane-treated Kevlar group) exhibited the highest fracture resistance (98.88 for untreated; 101.77 for silane-treated), highest impact strength (9.72 for untreated; 10.28 for silane- treated) and lowest surface roughness (0.5100 for untreated; 0.4911 for silane-treated) respectively. *Conclusions*: Subgroup 3 (5% Kevlar reinforcement with silane treatment) provided the most favorable combination of strength and surface characteristics.

Keywords: Kevlar fibers, PMMA resin, fracture resistance, impact strength, surface roughness, silane treatment.

INTRODUCTION

First introduced by Walter Wright and Vernon Brothers in 1937, in Philadelphia, Polymethylmethacrylate (PMMA) is the most common "material of choice" for fabricating various prostheses in dentistry. [1-3] Bestowed with appreciable aesthetic appeal, precise fit, ease of manipulation and affordability, this material documented a steady rise over the years, serving multipurpose applications in clinical practice.[3] However, scientific studies reported certain disadvantages with PMMA. Polymerization shrinkage was a major problem resulting in dimensional errors, especially in denture bases. Furthermore, leftover residual monomers could irritate oral mucous membranes, raising concerns about biocompatibility of the material. From a mechanical perspective, PMMA demonstrated

additional defects such as poor bonding ability, low fatigue resistance, and limited impact strength, which could result in denture fractures and functional failure. [4,5]

Regarding fracture resistance, PMMA reported suboptimal"outcome leading to high cost and high frequency of denture repairs performed each year.[6] Midline fracture was another inherent limitation that resulted due to flexural fatigue.[7] About 68% of impact strength failure due to sudden forceful impacts and accidental drops of denture were documented.[8] Sometimes denture break could occur within the mouth and initiate cracks due to stress concentration and torsional forces exerted during functional use.[9,10] This was attributed to low flexure modulus and reduced yield point distance of the material leading to low durability.[11,12]

PMMA also showed surface roughness with microbial colonization leading to discomfort and irritation. Discoloration and plaque retention could further impact the overall dental health reducing the aesthetic longevity of the prostheses. [13,14] Hence to overcome these constraints, few evidence based studies [15-19] aimed to modify the chemical structure of PMMA with reinforcing agents (fibers and fillers) of various shapes, sizes and concentrations. This led to the era of "Reinforcement of PMMA leading to the rapid development of specifically tailored polymers such as Aramid fibers, E-glass fibers, nylon fibers, zirconia, aluminum, tin, copper and other whisker-like structures of compounds such as TiO_2, ZnO, and Al_2O_3.[15-19] These could serve as a viable option for targeting key physiochemical characteristics for improving the longevity, functionality, and reliability of prostheses.[20] Moreover, recent advancements with computer-aided design and manufacturing (CAD/CAM) technology yielded high performance abilities with reinforced PMMA technique.[4] However, the fibers could only disrupt the homogenous acrylic resin matrix because of a poor fiber-resin contact, which affected impacted the mechanical properties. A study on the surface treatment of the fibers was conducted in an attempt to address this issue.[21] Pretreated with a silane-based adhesion promoter with ethanol or isopropanol solutions at concentrations of 90–95% were commonly deployed.[22] One study used more diluted solutions of silane (approximately 20% to 50%) on glass fibers to enhance the fracture resistance of interim fixed partial dentures.[23] Few studies inferred that Kevlar fiber reinforcement could surpass the nylon and E glass fibers due to its good mechanical adaptability, enhanced tensile strength and increased modulus of elasticity. [24-26] Additionally, it showed good biocompatibility and improved impact strength and fatigue resistance with no signs of toxicity, making it a most favorable choice for the present study. It is also considered as the most preferred choice for long term use in dental applications.[27] However, comparative studies wherein surface treatment of Kevlar fibers using silane coupling agents at different concentrations (2%, 3% & 5%) (w/w), and its effect to assess parameters such as fracture resistance, impact strength and surface roughness were scare in literature.

Based on the identification of this research gap, we formulated the Research gap question (RQ) as: "Does Kevlar fiber reinforced PMMA at different concentrations (2%, 3% & 5%) (w/w), both with and without silane surface treatment improve the fracture resistance, impact strength and surface roughness of Acrylic dentures?" We planned to bridge the gap by conducting a study to examine how the mechanical and surface characteristics of polymethylmethacrylate (PMMA) resin were affected by reinforcing with Kevlar fibers as well as to assess parameters such as fracture resistance, impact strength, and surface roughness, that contribute crucially to the evaluation of the material's performance, durability, and clinical applicability in dental prosthetic and restorative procedures.

MATERIAL AND METHODS

An invitro study was carried out after due permission from the ethical committee bearing the protocol number 675/2022-2023. This research study was conducted as per the "Helsinki Declaration of 1975, as revised in 2000". The "CRIS Guidelines (Checklist for Reporting In-vitro Studies)" were suitably followed for in-vitro research. A study conducted in 2022 by "Pradhan S et al" [14] evaluated the surface topography of Heat Cure Acrylic Denture-base Resin before and after Reinforcement with Different Fibers Using Stylus-based Profilometer" was considered as a reference/parent article for choosing the appropriate sample size.

The sample size calculation was:

n = 2 S 2 (Z 1+Z 2) 2
(M 1-M 2) 2

Considering the above and fixing a 5% level of significance with 80% power, total minimum calculated sample was 56 samples (8 samples per group; total 7 groups). Hence, we included total 189 samples with 63 samples each for Group A, Group B & Group C and 9 samples each for control group and subgroup 1 (2% w/w), subgroup 2 (3 % w/w) and subgroup 3 (5 % w/w). Power analysis was established by G * Power version 3.0.1) Franz Faul Universitat, Keil, Germany) yielded a power of 80% with $p<0.05$ (α error 0.05 & βerror 0.8). The null

hypothesis was set, stating "there was no difference fracture resistance, impact strength and surface roughness Kevlar fiber reinforced PMMA at different concentrations (2%, 3% & 5%) (w/w), both with and without silane surface treatment" and was tested at 0.05 level significance. A total of one hundred and eighty-nine samples (n=189) were included in the study. Balanced experimental approach with equal group sampling (n=63) was done among Group A (Fracture resistance), Group B (Impact Strength) & Group C (Surface roughness) that were further divided into control group with unreinforced PMMA (n=9) and six experimental groups (n=9) with Kevlar-reinforced PMMA at various concentrations (2%, 3% & 5%). Experimental groups were equally distributed into three untreated subgroups and three treated subgroups with silane coupling agent; Subgroup 1-2%w/w; Subgroup 2- 3%w/w & Subgroup 3- 5%w/w.

Preparation of Mold: Wax blocks (Prime Dental Products Pvt Limited; ISO 13485:2016) with predefined dimensions (3 X 4.5 X 50 mm) for fracture resistance (Group A) and impact strength (Group B) and discs (10 X 2 mm) for surface roughness (Group C) were used to manufacture dental plaster molds. A thin layer of petroleum jelly (Vasa Cosmetics Pvt Ltd; ISO 9001:2015) was applied. Before being used, the Kevlar fibers (Shreeji Techno Innovations, Ahmedabad, Gujrat) were trimmed using scissors into lengths of 0.5 ± 0.1 mm. [Figure 1A]

Control group: Two milliliters of monomer (D.D. Enterprise) and five grams of PMMA polymer powder (D.D. Enterprise) were combined. After the mixture reaches the dough stage, it is kneaded and filled into the mold. A hydraulic press (Siro Dental Division, Italy) was used to close the trial under 100 psi of pressure. Extra flash was cut out. After being clamped, the flask was allowed to cure (Wassermann- Dental Maschinen, Hamburg, Germany; DIN EN ISO 9001: 2008) on a bench. The flasks were submerged in boiling water and kept at 80°C for 45 minutes. The flasks were bench cured to room temperature following polymerization and then deflasked.

Experimental group: To ensure uniformity, each group employs the same monomer volume (2 mL) and total polymer-fiber weight (5 g) as the control group. [Figure 1B]
Subgroup 1 (2% Fiber Reinforcement): 4.90 g of PMMA powder and 0.10 g of Kevlar fiber were mixed together and processed.
Subgroup 2 (3% Fiber Reinforcement): 4.85 g of PMMA powder and 0.15 g of Kevlar fiber were mixed together & combined with two milliliters of monomer and processed as necessary.
Subgroup 3 (5% Fiber Reinforcement): 4.75 g of PMMA powder and 0.25 g of Kevlar fiber were mixed together and mixed with two milliliters of monomer and treated in the same way as the other groups.

Fiber surface treatment: After being immersed in silane (Fusion-Duralink® Angelus® Bonding Agent), the fibers were allowed to air dry for 20 minutes. To improve bonding with PMMA, fibers were immersed in monomer for ten minutes after drying. The fibers treated with silane and monomer were then mixed with PMMA powder according to group-specific ratios. The resin dough was removed from the mixing jar, placed inside the mold, and bench pressed using a hydraulic press (Hydraulic Press P 400, Sirio Dental Division), gradually applying pressure. After submerging the clamped mold in room temperature water (23 +/- 2°C), it was gradually elevated to 80°C and kept there for 45 minutes. [Figure 1C] The finishing & polishing was done..

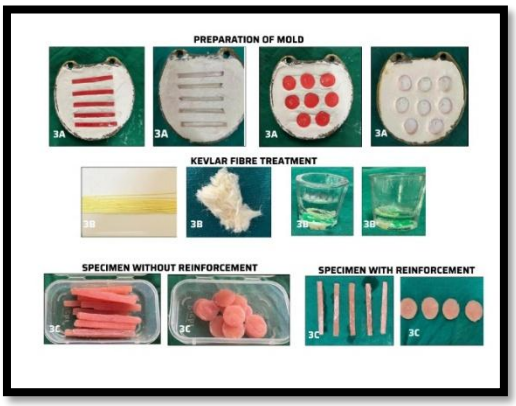


Figure 1: Methodology of the study

Testing procedures: The Universal Testing Machine (UTM) (Instron, Tinius Olsen, Shimadzu, Zwick Roell Group, and

Anton Paar) was used to measure fracture resistance for all six experimental groups. The test was conducted using a pendulum with a 2-joule capacity. The impact energy absorbed during the quick blow was shown immediately on the scale in joules as the energy needed to fracture the specimen upon impact. A contact-type profilometer (Taylor Hobson, Mitutoyo, Bruker, and KLA Corporatio; ISO 9001:2015) was used to measure surface roughness. Under a constant stylus force of four millinewtons (mN), each disc-shaped object was scanned at three different spots on its surface. Based on the average of the three recorded values, the device determined the average surface roughness (Ra, in micrometers).

Statistical analysis: Microsoft Excel version 13 was used to collect and enter the data.
IBM Statistical Package for Social Science version 21 was used to statistically evaluate the data. The mean and standard deviation for continuous variables were obtained in order to compare the parameters between Post Hoc Tukey's Groups Analysis of Variance.
A 95% confidence range was used for each statistical test, and a value of $p<0.05$ was considered statistically significant.

RESULTS

One-way analysis of variance (ANOVA) revealed a significant difference for fracture resistance ($F = 62.925$, $p < 0.001$), impact strength ($F = 61.501$, $p < 0.001$) and surface roughness ($F = 10.170$, $p < 0.001$) respectively. The control group with untreated PMMA had the lowest mean fracture resistance of about 84.97 units (SD=3.36) and lowest mean impact strength, at roughly 7.29 units (SD= 0.48). The mean surface roughness of 0.5222 units (SD = 0.02906) was reported by the control group. However, the addition of Kevlar fibers, particularly when silane-treated, improved fracture resistance. For the subgroup 1 (2% Kevlar fiber-reinforced PMMA), the mean values increased to 91.98 (untreated) and 94.23 (silane-treated); subgroup 2 (3% Kevlar fiber-reinforced PMMA), it showed 95.78 (untreated) and 98.53 (silane-treated); and for the subgroup 3 (5% Kevlar fiber-reinforced PMMA), they increased to 98.88 (untreated) and 101.77 (silane-treated) [Figure 2].

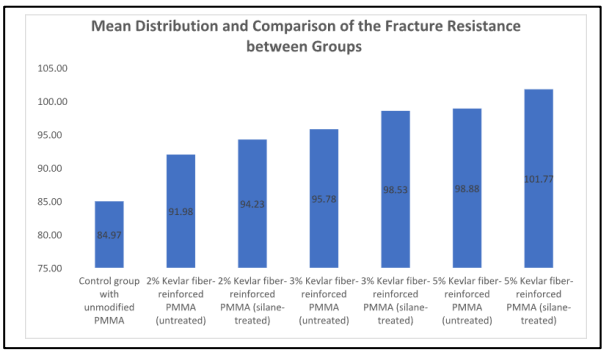


Figure 2: Mean Distribution and Comparison of the Fracture Resistance between Groups

These findings clearly illustrate that PMMA's mechanical strength is maximized by the quantity of Kevlar fibers and the use of silane treatment. Similarly, the impact strengths also increased gradually. The subgroup 1 (2% untreated and silane-treated Kevlar fiber-reinforced PMMA) had means of roughly 8.19 and 8.76, respectively; the subgroup 2 (3% Kevlar fiber-reinforced PMMA) had means of roughly 8.88 (untreated) and 9.46 (silane-treated); and the subgroup 3 (5% Kevlar fiber-reinforced PMMA) increased further to roughly 9.72 (untreated) and 10.28(silane-treated) [Figure 3].

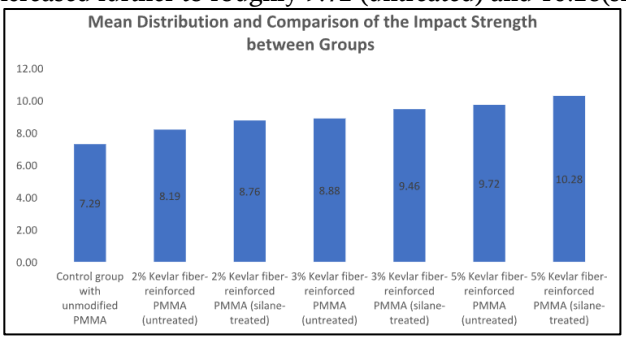
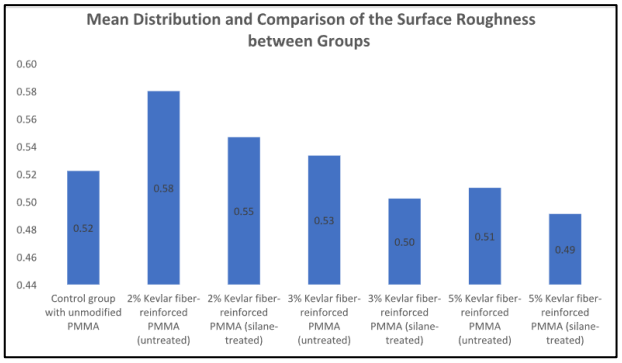


Figure 3: Mean Distribution and Comparison of the Impact Strength between Groups

In case of surface roughness, the addition of 2% Kevlar fibers without silane treatment significantly raised surface

roughness to 0.5800, showing a statistically substantial rise in surface irregularity (mean difference = − 0.05778, p = 0.001) [Figure 4]



The mean roughness marginally dropped to 0.5467 after silane treatment at a 2% fiber concentration, but it was still higher than the control. However, both the untreated and silane-treated groups displayed increasingly smoother surfaces as the fiber content rose to 3% and 5%. In particular, the 5% groups displayed mean roughness values of 0.5100 (untreated) and 0.4911 (silane-treated), whereas the 3% Kevlar groups displayed mean roughness values of 0.5333 (untreated) and 0.5022 (silane-treated). This trend suggests that surface smoothness approached or perhaps exceeded that of the untreated PMMA at larger concentrations of Kevlar fibers, especially when silane-treated.

The Tukey HSD post hoc comparisons & pairwise comparisons between the fiber-reinforced groups demonstrated that silane treatment tends to increase fracture resistance and impact strengths with mean difference between the control group and the subgroup 3 was –16.80, $p < 0.001$ [Table 1] & $p < 0.001$ in all cases. [Table 2 & 3]

Figure 4: Mean Distribution and Comparison of the Surface Roughness between Groups

Multiple Comparisons						
Dependent Variable: Fracture Resistance						
Tukey HSD						
(I) Groups	**(J) Groups**	**Mean Difference (I-J)**	**Std. Error**	**P Value**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Control group with unmodified PMMA	2% Kevlar fiber- reinforced PMMA (untreated)	-7.01111	.98760	.000	- 10.0312	-3.9910
	2% Kevlar fiber-reinforced PMMA (silane-treated)	-9.26667	.98760	.000	- 12.2867	-6.2466
	3% Kevlar fiber- reinforced PMMA (untreated)	-10.81111	.98760	.000	- 13.8312	-7.7910
	3% Kevlar fiber-reinforced PMMA (silane-treated)	-13.56667	.98760	.000	- 16.5867	- 10.5466
	5% Kevlar fiber- reinforced PMMA (untreated)	-13.91111	.98760	.000	- 16.9312	- 10.8910

	5% Kevlar fiber-reinforced PMMA (silane-treated)	-16.80000	.98760	.000	- 19.8201	- 13.7799
2% Kevlar fiber-reinforced PMMA (untreated)	2% Kevlar fiber-reinforced PMMA (silane-treated)	-2.25556	.98760	.270	-5.2756	.7645
	3% Kevlar fiber-reinforced PMMA (untreated)	-3.80000	.98760	.005	-6.8201	-.7799
	3% Kevlar fiber-reinforced PMMA (silane-treated)	-6.55556	.98760	.000	-9.5756	-3.5355
	5% Kevlar fiber-reinforced PMMA (untreated)	-6.90000	.98760	.000	-9.9201	-3.8799
	5% Kevlar fiber-reinforced PMMA (silane-treated)	-9.78889	.98760	.000	-12.8090	-6.7688
2% Kevlar fiber-reinforced PMMA (silane- treated)	3% Kevlar fiber- reinforced PMMA (untreated)	-1.54444	.98760	.705	-4.5645	1.4756
	3% Kevlar fiber- reinforced PMMA (silane-treated)	-4.30000	.98760	.001	-7.3201	-1.2799
	5% Kevlar fiber- reinforced PMMA (untreated)	-4.64444	.98760	.000	-7.6645	-1.6244
	5% Kevlar fiber- reinforced PMMA (silane-treated)	-7.53333	.98760	.000	- 10.5534	-4.5133
3% Kevlar fiber-reinforced PMMA (untreated)	3% Kevlar fiber- reinforced PMMA (silane-treated)	-2.75556	.98760	.096	-5.7756	.2645
	5% Kevlar fiber- reinforced					

	PMMA (untreated)	-3.10000	.98760	.041	-6.1201	-.0799
	5% Kevlar fiber- reinforced PMMA (silane-treated)	-5.98889	.98760	.000	-9.0090	-2.9688
3% Kevlar fiber-reinforced PMMA (silane- treated)	5% Kevlar fiber- reinforced PMMA (untreated)	-.34444	.98760	1.000	-3.3645	2.6756
	5% Kevlar fiber- reinforced PMMA (silane-treated)	-3.23333	.98760	.028	-6.2534	-.2133
5% Kevlar fiber-reinforced PMMA (untreated)	5% Kevlar fiber- reinforced PMMA (silane-treated)	-2.88889	.98760	.070	-5.9090	.1312

Table 1. Pairwise Comparison of the Fracture Resistance between Groups

Multiple Comparisons						
Dependent Variable: Impact Strength						
Tukey HSD						
(I) Groups	**(J) Groups**	**Mean Difference (I-J)**	**Std. Error**	**P Value**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Control group with unmodified PMMA	2% Kevlar fiber-reinforced PMMA (untreated)	-.90000	.18027	.000	-1.4513	-.3487
	2% Kevlar fiber-reinforced PMMA (silane-treated)	-1.46667	.18027	.000	-2.0179	-.9154
	3% Kevlar fiber-reinforced PMMA (untreated)	-1.58889	.18027	.000	-2.1401	-1.0376
	3% Kevlar fiber-reinforced PMMA (silane- treated)	-2.16667	.18027	.000	-2.7179	-1.6154
	5% Kevlar fiber-reinforced PMMA (untreated)	-2.43333	.18027	.000	-2.9846	-1.8821
	5% Kevlar fiber-reinforced PMMA (silane- treated)	-2.98889	.18027	.000	-3.5401	-2.4376
2% Kevlar fiber- reinforced PMMA (untreated)	2% Kevlar fiber-reinforced PMMA (silane- treated)	-.56667	.18027	.040	-1.1179	-.0154
	3% Kevlar fiber-reinforced PMMA (untreated)	-.68889	.18027	.006	-1.2401	-.1376
	3% Kevlar fiber-reinforced PMMA (silane- treated)	-1.26667	.18027	.000	-1.8179	-.7154

	5% Kevlar fiber-reinforced PMMA (untreated)	-1.53333	.18027	.000	-2.0846	-.9821
	5% Kevlar fiber-reinforced PMMA (silane- treated)	-2.08889	.18027	.000	-2.6401	-1.5376
2% Kevlar fiber- reinforced PMMA (silane- treated)	3% Kevlar fiber-reinforced PMMA (untreated)	-.12222	.18027	.993	-.6735	.4290
	3% Kevlar fiber-reinforced PMMA (silane-treated)	-.70000	.18027	.005	-1.2513	-.1487
	5% Kevlar fiber-reinforced PMMA (untreated)	-.96667	.18027	.000	-1.5179	-.4154
	5% Kevlar fiber-reinforced PMMA (silane-treated)	-1.52222	.18027	.000	-2.0735	-.9710
3% Kevlar fiber- reinforced PMMA (untreated)	3% Kevlar fiber-reinforced PMMA (silane- treated)	-.57778	.18027	.034	-1.1290	-.0265
	5% Kevlar fiber-reinforced PMMA (untreated)	-.84444	.18027	.000	-1.3957	-.2932
	5% Kevlar fiber-reinforced PMMA (silane- treated)	-1.40000	.18027	.000	-1.9513	-.8487
3% Kevlar fiber- reinforced PMMA (silane- treated)	5% Kevlar fiber-reinforced PMMA (untreated)	-.26667	.18027	.756	-.8179	.2846
	5% Kevlar fiber-reinforced PMMA (silane- treated)	-.82222	.18027	.001	-1.3735	-.2710
5% Kevlar fiber- reinforced PMMA (untreated)	5% Kevlar fiber-reinforced PMMA (silane- treated)	-.55556	.18027	.047	-1.1068	-.0043
2% Kevlar fiber-reinforced PMMA (untreated)	2% Kevlar fiber-reinforced PMMA (silane-treated)	-2.25556	.98760	.270	-5.2756	.7645
	3% Kevlar fiber-reinforced PMMA (untreated)	-3.80000	.98760	.005	-6.8201	-.7799
	3% Kevlar fiber-reinforced PMMA (silane-treated)	-6.55556	.98760	.000	-9.5756	-3.5355
	5% Kevlar fiber-					

	reinforced PMMA (untreated)	-6.90000	.98760	.000	-9.9201	-3.8799
	5% Kevlar fiber-reinforced PMMA (silane-treated)	-9.78889	.98760	.000	-12.8090	-6.7688
2% Kevlar fiber-reinforced PMMA (silane- treated)	3% Kevlar fiber- reinforced PMMA (untreated)	-1.54444	.98760	.705	-4.5645	1.4756
	3% Kevlar fiber- reinforced PMMA (silane-treated)	-4.30000	.98760	.001	-7.3201	-1.2799
	5% Kevlar fiber- reinforced PMMA (untreated)	-4.64444	.98760	.000	-7.6645	-1.6244
	5% Kevlar fiber- reinforced PMMA (silane-treated)	-7.53333	.98760	.000	- 10.5534	-4.5133
3% Kevlar fiber-reinforced PMMA (untreated)	3% Kevlar fiber- reinforced PMMA (silane-treated)	-2.75556	.98760	.096	-5.7756	.2645
	5% Kevlar fiber- reinforced PMMA (untreated)	-3.10000	.98760	.041	-6.1201	-.0799
	5% Kevlar fiber- reinforced PMMA (silane-treated)	-5.98889	.98760	.000	-9.0090	-2.9688
3% Kevlar fiber-reinforced PMMA (silane- treated)	5% Kevlar fiber- reinforced PMMA (untreated)	-.34444	.98760	1.000	-3.3645	2.6756
	5% Kevlar fiber- reinforced PMMA (silane-treated)	-3.23333	.98760	.028	-6.2534	-.2133
5% Kevlar fiber-reinforced PMMA (untreated)	5% Kevlar fiber- reinforced PMMA (silane-treated)	-2.88889	.98760	.070	-5.9090	.1312

Table 2. Pairwise Comparison of the Impact Strength between Groups

Multiple Comparisons						
Dependent Variable: Surface Roughness						
Tukey HSD						
(I) Groups	**(J) Groups**	**Mean Difference (I-J)**	**Std. Error**	**P Value**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Control group with unmodified PMMA	2% Kevlar fiber-reinforced PMMA (untreated)	-.05778	.01336	.001	-.0986	-.0169
	2% Kevlar fiber-reinforced PMMA (silane-treated)	-.02444	.01336	.535	-.0653	.0164
	3% Kevlar fiber-reinforced PMMA (untreated)	-.01111	.01336	.981	-.0520	.0298
	3% Kevlar fiber-reinforced PMMA (silane-treated)	.02000	.01336	.746	-.0209	.0609
	5% Kevlar fiber-reinforced PMMA (untreated)	.01222	.01336	.969	-.0286	.0531
	5% Kevlar fiber-reinforced PMMA (silane-treated)	.03111	.01336	.249	-.0098	.0720
2% Kevlar fiber- reinforced PMMA (untreated)	2% Kevlar fiber-reinforced PMMA (silane-treated)	.03333	.01336	.181	-.0075	.0742
	3% Kevlar fiber-reinforced PMMA (untreated)	.04667	.01336	.015	.0058	.0875
	3% Kevlar fiber-reinforced PMMA (silane-treated)	.07778	.01336	.000	.0369	.1186
	5% Kevlar fiber-reinforced PMMA (untreated)	.07000	.01336	.000	.0291	.1109
	5% Kevlar fiber-reinforced PMMA (silane-treated)	.08889	.01336	.000	.0480	.1298
2% Kevlar fiber- reinforced PMMA (silane- treated)	3% Kevlar fiber-reinforced PMMA (untreated)	.01333	.01336	.952	-.0275	.0542
	3% Kevlar fiber-reinforced PMMA (silane-treated)	.04444	.01336	.025	.0036	.0853
	5% Kevlar fiber-reinforced PMMA (untreated)	.03667	.01336	.106	-.0042	.0775
	5% Kevlar fiber-reinforced PMMA (silane-treated)	.05556	.01336	.002	.0147	.0964
3% Kevlar fiber- reinforced	3% Kevlar fiber-reinforced PMMA (silane-treated)	.03111	.01336	.249	-.0098	.0720

PMMA (untreated)	5% Kevlar fiber-reinforced PMMA (untreated)	.02333	.01336	.589	-.0175	.0642
	5% Kevlar fiber-reinforced PMMA (silane-treated)	.04222	.01336	.038	.0014	.0831
3% Kevlar fiber- reinforced PMMA (silane- treated)	5% Kevlar fiber-reinforced PMMA (untreated)	-.00778	.01336	.997	-.0486	.0331
	5% Kevlar fiber-reinforced PMMA (silane-treated)	.01111	.01336	.981	-.0298	.0520
5% Kevlar fiber- reinforced PMMA (untreated)	5% Kevlar fiber-reinforced PMMA (silane-treated)	.01889	.01336	.792	-.0220	.0598

Table 3. Pairwise Comparison of the Surface Roughness between Groups

DISCUSSION

Based on the objective of the present study, PMMA showed enhanced properties, when reinforced with Kevlar fibers at varying concentrations. The study inferred that Kevlar fibers increased the stiffness and flexural strength, absorbed impact energy, maintained light weight and workability of PMMA, thereby making it resistance to repetitive and sudden forces during accidental drops or fractures and preventing permanent deformation. Additionally, the crack-arresting nature of Kevlar fibers prevents the growth of internal flaws, reducing the likelihood of fracture under cyclic loading. Furthermore, the low density of these fibers makes it comfortable for the patient as the prosthesis is light weight and non-bulky, thereby increasing the mechanical durability and long-term extended service life with fewer repair visits. Being chemically inert, it did not provoke any reactions and imparted better fiber matrix interaction with silane treatment. Hence it improved the clinical longevity, reinforced toughness without added bulk, increased crack resistance and proved to be biocompatible and safe for intraoral use. These findings were consistent with those of John et al. [28] in 2001 and Vallittu et al. [29] in 1996, who found that the flexural strength of heat-polymerized PMMA resin was significantly improved by Kevlar fibers when compared to unreinforced resin and those reinforced with nylon fibers. Furthermore, Karacaer et al. [30] in 2003 inferred that the length & concentration of reinforcing fibers had a significant influence on the material's final strength. Stipho (1998) observed similar outcomes when glass fibers were added to autopolymerizing PMMA, with the most impacts occurring at higher concentrations of 5-7%. [31] These results were corroborated by the study's present findings. Vallittu in 1996 emphasized the importance of fiber orientation, stating that unidirectional arrangement parallel to stress application produces the best reinforcement.[29] Although the fibers in the present research were short fibers that were manually added, giving them a random orientation of multidirectional stress distribution, the mechanical results were still noticeably superior to the control.

The impact strength of PMMA was evaluated using Kevlar and polyethylene fibers by Kamath and Bhargava et al. in 2002 [24]. They found that Kevlar is more effective and offers greater impact resistance because of its inherent high tensile strength and energy-absorbing capacity. Similar improvements with aramid fibers and other woven fibers were demonstrated by Uzun et al. [32] in 1999, indicating that woven or randomly oriented short fibers continue to provide significant reinforcing.

Although the mechanical qualities improved with the addition of Kevlar fibers, there was initially a modest increase in surface roughness, especially at lower fiber concentrations without silane treatment. Nevertheless, surface roughness gradually decreased with increasing concentrations of silane application, producing a smoother and more clinically advantageous surface.This outcome was consistent with research by Ellakwa et al. [33] (2002). In our study, the silane-treated groups showed smoother surfaces than the untreated groups, perhaps as a result of better fiber integration and fewer voids. This study demonstrated improved mechanical property performance using the silane surface treatment method. This outcome was consistent with the findings of Ellakwa et al. [33] (2002). Additionally, it closes gaps that could jeopardize structural integrity. Additionally, when full dentures are reinforced with E-glass fibers, Kim and Watts (2004) demonstrated the significance of fiber pretreatment in obtaining the best bonding and fracture resistance. [34]

However, there were few limitations. Since the study was conducted under controlled laboratory conditions, it could not fully replicate the complex intraoral environment. It did not include standard operating procedures (thermal cycling or water aging), thereby simulating long-term oral use. These processes can influence both fiber- matrix integrity and surface characteristics. Moreover, the fibers were mixed manually with random orientation within the PMMA matrix. A uniform, directional alignment may have provided even greater mechanical reinforcement. The standardized rectangular bar specimens may not fully reflect the anatomical shape and stress distribution in actual denture bases or clinical prostheses. Future research can be conducted on stimulated models depicting intraoral conditions reflecting the actual anatomy and unidirectional stress distribution.

CONCLUSION: Kevlar fibers are unique because of their outstanding tensile strength, resistance to fatigue, and biocompatibility. Kevlar fiber reinforcement significantly improved both fracture and impact strength compared to unmodified PMMA.

Author Contributions:

Concepts: Dr Jagruti Somani; Design: Dr Ajay Gaikwad & Dr Pronob Saniyal; Definition of intellectual content: Dr Jagruti Somanai, Dr Ajay Gaikwad & Dr Pronob Saniyal; Investigation: Dr Jagruti Somani; Manuscript writing: Dr Jagruti Somani; Editing & reviewing: Dr Ajay Gaikwad & Dr Pronob Saniyal

Financial support and sponsorship:
Krishna Vishwa Vidyapeeth (KVV), Karad
Conflict of Interest:
The authors declare that they have no competing interests

REFERENCES

1. Improving PMMA resin using graphene oxide for a definitive prosthodontic rehabilitation-A clinical report. Journal of clinical and experimental dentistry. 2019 Jul;11(7):e670.
2. Mahalaxmi S. Materials used in Dentistry. Wolters Kluwer india Pvt Ltd; 2020 Apr 1.
3. Agarwalla SV, Malhotra R, Rosa V. Translucency, hardness and strength parameters of PMMA resin containing graphene-like material for CAD/CAM restorations. Journal of the Mechanical Behavior of Biomedical Materials. 2019 Dec 1;100:103388.
4. Turagam N, Prasad Mudrakola D. Effect of Micro-Additions of Carbon Nanotubes to Polymethylmethacrylate on Reduction in Polymerization Shrinkage. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2013 Feb;22(2):105-11.
5. Matsuo H, Suenaga H, Takahashi M, Suzuki O, Sasaki K, Takahashi N. Deterioration of polymethyl methacrylate dentures in the oral cavity. Dental materials journal. 2015 Mar 27;34(2):234-9.
6. Jagger DC, Harrison A, Jandt KD. The reinforcement of dentures. J Oral Rehabil. 1999 Mar;26(3):185-94.
7. MathewE and Wain EA, Stresses in denture base.Br.Dent.J 1956;100:167-70.
8. Johnston EP, Nicholls JI, Smith DE. Flexure fatigue of 10 commonly used denture base resins. J Prosthet Dent. 1981;46:478–483.
9. Smith DC. Recent developments and prospects in dental polymers. The Journal of Prosthetic Dentistry. 1962 Nov 1;12(6):1066-78.
10. Stafford GD, Lewis TT, Huggett R. Fatigue testing of denture base polymers. J Oral Rehabil. 1982 Mar;9(2):139-54.
11. Diaz-Arnold AM, Vargas MA, Shaull KL, Laffoon JE, Qian F. Flexural and fatigue strengths of denture base resin. J Prosthet Dent. 2008 Jul;100(1):47-51.
12. Fujii K. Fatigue properties of acrylic denture base resins. Dent Mater J. 1989 Dec;8(2):243-59.
13. Dantas LC, da Silva-Neto JP, Dantas TS, Naves LZ, das Neves FD, da Mota AS. Bacterial Adhesion and Surface Roughness for Different Clinical Techniques for Acrylic Polymethyl Methacrylate. Int J Dent. 2016;2016:8685796. doi: 10.1155/2016/8685796.
14. Pradhan S, Mathuriya S, Sonkesriya S, Maheshwari A, Gaur G, Choubey A. Evaluation of Surface Topography of Heat Cure Acrylic Denture-base Resin before and after Reinforcement with Different Fibers Using Stylus-based Profilometer. J Contemp Dent Pract. 2022 Apr 1;23(4):415-418.
15. Messermith PB, Giannelis EP. Synthesis and characterization of layered silicate epoxy Nano composites. Chem Mater 1994; 6:1719-25.
16. Huang X, Yin Z, Wu S, Qi X, He Q, Zhang Q, Yan Q, Boey F, Zhang H.Graphene-Based Materials: Synthesis, Characterization, Properties, and Applications. Small. 2011;7(14): 1876-902.
17. I. Roy, M.K. Stachowiak,E.J.Bergey, "Nonviral gene transfection nanoparticles: function and applications in the brain" Nanomedicine: Nanotechnology, Biology, and Medicine 2008;4(2): 89-97.
18. X.M.Li,Q. Feng, R.Cui."The use of nanoscaled fibres or tubes to improve biocompatibility and bioactivity of biomedical materials," Journal of Nanomaterial's, 2013;13:110-136.
19. Jordan J,JacobKL, TannenbaumR, ShartMA, Jasiuk I. Experimental trends in polymer

Nan composites-A review.MaterSciEng 2005;393(1): 1-11.
20. Gamal R, Gomaa YF, Said AM. Incorporating nano graphene oxide to poly-methyl methacrylate; antibacterial effect and thermal expansion. Journal of Modern Research. 2019 Jul 1;1(1):19-23.
21. Mowade TK, Dange SP, Thakre MB, Kamble VD. Effect of fiber reinforcement on impact strength of heat polymerized polymethyl methacrylate denture base resin: in vitro study and SEM analysis. J Adv Prosthodont. 2012 Feb;4(1):30-6.
22. Solnit GS. The effect of methyl methacrylate reinforcement with silane- treated and untreated glass fibers. The Journal of prosthetic dentistry. 1991 Sep 1;66(3):310-4.
23. Basant G, Reddy YG. The effect of incorporation, orientation and silane treatment of glass fibers on the fracture resistance of interim fixed partial dentures. J Indian Prosthodont Soc. 2011 Mar;11(1):45-51.
24. Kamath G, Bhargava K. Comparison of impact strength of acrylic resin reinforced with kevlar and polyethylene fibres. Indian J Dent Res. 2002 Apr-Jun;13(2):108-11.
25. Almaroof AG, Thyab SA, Ali AH. Bond strength of a new Kevlar fiber- reinforced composite post with semi-interpenetrating polymer network (IPN) matrix. J Clin Exp Dent. 2019 Aug 1;11(8):e695-e700.
26. Algahtani A. Manufacturing Of High Strength Kevlar Fibers. King Khalid University. Manufacturing Of High Strength Kevlar Fibers. Diunduh pada. 2018 Oct 5;22:00.
27. Alla RK, Sajjan S, Alluri VR, Ginjupalli K, Upadhya N. Influence of fiber reinforcement on the properties of denture base resins. Journal of biomaterials and nanobiotechnology. 2013 Jan 17;4(1):91-7.
28. John J, Gangadhar SA, Shah I. Flexural strength of heat-polymerized polymethyl methacrylate denture resin reinforced with glass, aramid, or nylon fibers. J Prosthet Dent. 2001 Oct;86(4):424-7.
29. Vallittu PK. A review of fiber-reinforced denture base resins. J Prosthodont. 1996 Dec;5(4):270-6.
30. Karacaer O, Polat TN, Tezvergil A, Lassila LV, Vallittu PK. The effect of length and concentration of glass fibers on the mechanical properties of an injection- and a compression-molded denture base polymer. J Prosthet Dent. 2003 Oct;90(4):385-93.
31. Stipho HD. Effect of a glass fiber reinforcement on some mechanical properties of autopolymerizing polymethyl metactylate. J Prosthet Dent 1998;79:580–4.
32. Uzun G, Hersek N, Tinçer T. Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resin. J Prosthet Dent. 1999 May;81(5):616-20.
33. Ellakwa AE, Shortall AC, Marquis PM. Influence of fiber type and wetting agent on the flexural properties of an indirect fiber reinforced composite. J Prosthet Dent. 2002 Nov;88(5):485-90.
34. Kim SH, Watts DC. The effect of reinforcement with woven E-glass fibers on the impact strength of complete dentures fabricated with high- impact acrylic resin. The journal of prosthetic dentistry. 2004 Mar 1;91(3):274-80

