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Effect of different surface treatments and the novel cyclophatic comonomer on the bond strength of acrylic denture teeth to PMMA Denture Base

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Abstract

Statement of problem: Implant-supported acrylic hybrid prostheses offer masticatory efficiency and biting force, significantly greater than the conventional complete dentures or implant-supported overdentures. However, they also introduce mechanical challenges, especially related to debonding of teeth from the resin base, due to the increased load and reduced thickness of the overlying acrylic resin. The repair involves extensive clinical and laboratory procedure hence there is an enhanced need to improve bond strength of tooth to denture base material.

Aim of the study: To assess the bond strength between PMMA denture base incorporated with 20% and 25% cycloaliphatic comonomer and acrylic denture teeth after three different surface treatments.

Material and methodology: Seventy-two acrylic resin maxillary central incisor teeth were divided into four subgroups; subgroup A- no treatment, subgroup B- surface roughening by tungsten carbide bur, subgroup C- air abrasion with 120-μm Al_2O_3, subgroup D- MMA priming. Three denture base resins were prepared: unmodified PMMA, PMMA with 20% cycloaliphatic comonomer, and PMMA with 25% cycloaliphatic comonomer. Rectangular wax blocks (36 × 12 × 5 mm) were fabricated, and each tooth was positioned with a 1-mm exposed cervical area and a standardized 45° long-axis inclination before processing with the assigned resin. All 72 specimens were acrylized, finished, polished, and subjected to thermocycling. Shear bond strength testing was then performed using a universal testing machine.

Conclusion: Within the limitations of the present study, it is concluded that: The highest bond strength among the groups without any surface treatment was observed in heat-cure PMMA with 25% copolymer, showing a ninefold increase compared to conventional PMMA. In PMMA modified with 20% copolymer and 25% copolymer, surface treatment of teeth with air abrasion showed significantly higher bond strength.

Keyword: Denture Base, Dental Prostheses, Polymethyl Methacrylate, Methyl Methacrylate.

Introduction

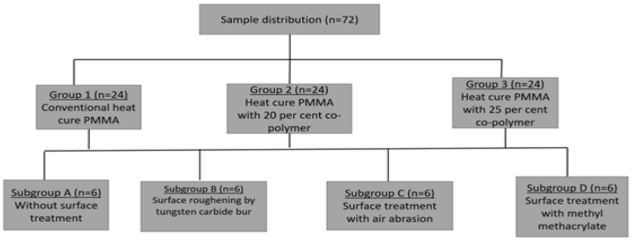
Polymethyl methacrylate (PMMA) has been widely used for manufacturing denture bases in conglomeration with artificial teeth for a variety of dental prostheses. Debonding of acrylic resin teeth from the PMMA denture base is the most frequently encountered unresolved failure. Factors affecting the bond strength of tooth to PMMA denture base include improper wax elimination from the ridge lap area of the teeth, impetuous application of the separating medium, monomer deficiency during processing, polymerization method employed, water sorption, coefficient of thermal expansion, porosity at the junction of denture base and teeth and the type of cross-linking agents added in the methyl methacrylate (MMA).[1]

It has been estimated that between 22% and 30% of denture repairs involves tooth debonding, usually in the anterior region of the denture.[2]Prior studies have reported a wide disparity of biting force on the anterior teeth between natural dentition and acrylic prosthesis such as complete dentures, removable partial dentures, or hybrid prosthesis.[1] In implant-supported prosthodontics, hybrid prostheses—particularly those following the All on-Four concept—are a popular choice. These fixed dentures offer high masticatory efficiency and biting force, significantly greater than traditional complete dentures or implant-supported overdentures. However, they also introduce mechanical challenges, especially related to debonding of teeth from the resin base, due to the increased load and reduced thickness of the overlying acrylic resin. The repair involves extensive procedure therefore there is an enhanced need to improve bond strength of tooth to denture base material.

Several attempts have been made by researchers to enhance bond strength between acrylic resin teeth and denture base materials. Mechanical preparation of the tooth surface, etching it with chemicals, or wetting it with organic solvents were done to obtain reliable bond strength. Further, a covalent bond was established by grinding and then wetting the surface of the denture tooth with methyl methacrylate (MMA) monomer. Airborne-particle abrasion and laser irradiation was also used to alter the surface for better bonding.[3] Recently monomeric modification have been executed to improvise the properties of denture base resins. A newly identified cycloaliphatic cross-linking comonomer, tricyclodecane dimethanol diacrylate (TCDDMDA), has been copolymerized with PMMA which exhibited better bond strength and biocompatibility than the conventional PMMA.[4]

Materials and methodology

Three groups of PMMA were prepared.



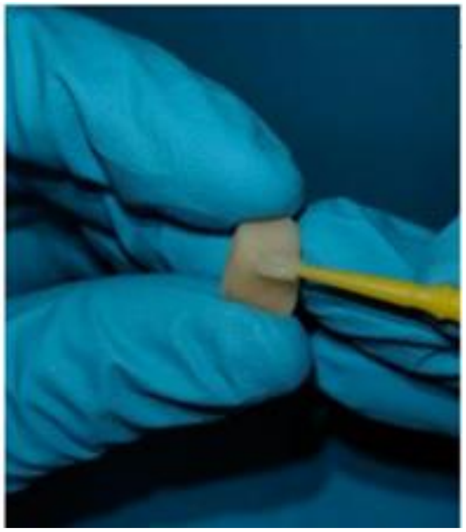
Seventy-two acrylic resin denture teeth (central incisor of mould size S-24) were used for all the test groups. The denture teeth were divided into four groups consisting of twenty-four teeth in each group

Subgroup A: No surface treatment was done.

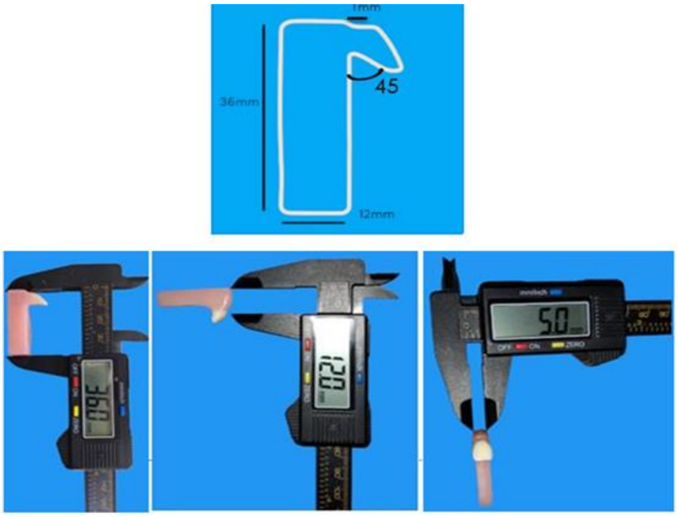
Subgroup B: Were roughened by grinding with a tungsten carbide bur at a speed of 15,000 rpm for 10 sec.

Subgroup C: Were modified by air abrasion on the ridge lap surfaces with 120 micro-meter aluminium oxide (Al_2O_3) particles at 2 bar for 10 sec. Application distance was set at 10 mm. After airborne-particle abrasion for removing remnants, the specimens were placed under running tap water and then dried with oil-free compressed air.

Subgroup D: The specimens were primed with MMA monomer for 30 seconds.

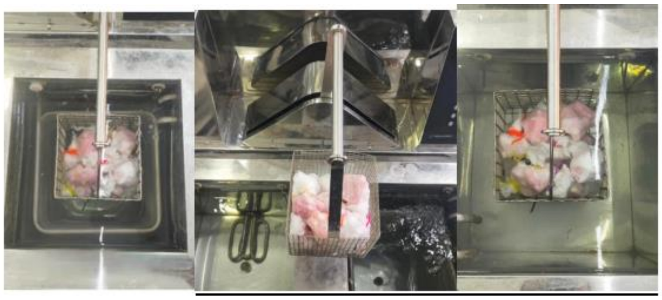


Seventy two rectangular wax blocks measuring ($36 \times 12 \times 5$ mm^3) were fabricated, and teeth were attached to them with a 1-mm high cervical area so that the denture base area surrounding the teeth was waxed up circumferentially comprising the neck and the mesiodistal portions. In addition, the long axis of the teeth were adjusted to 45° to the wax block surface mesially and distally using a protractor. The waxed models were acrylized, processed, finished, and polished to obtain 72 specimens.

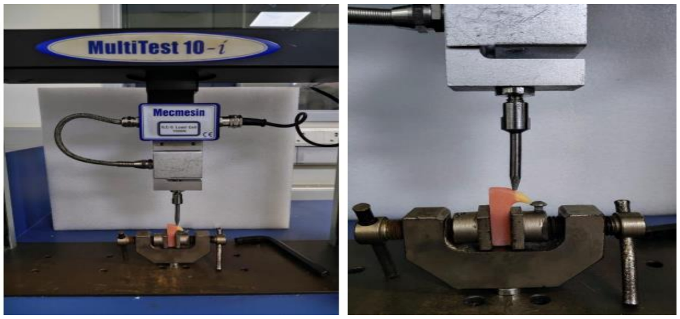


Sample dimensions

Thermocycling was performed to simulate 1 year of intraoral aging: specimens underwent 1000 cycles between 5°C and 55°C, with a dwell time of 30 seconds, using a Holmarc Thermocycler HO-THC-01. Shear bond strength testing was conducted using the Instron Electropuls E3000 universal testing machine. Load was applied along the long axis of the tooth at a crosshead speed of 2 mm/min, and bond strength was calculated using the formula: S = F / A, where S = shear strength, F = applied force, and A = bonding area.



Thermocycling



Shear Bond Strength Test of Samples

Results

Table 1:

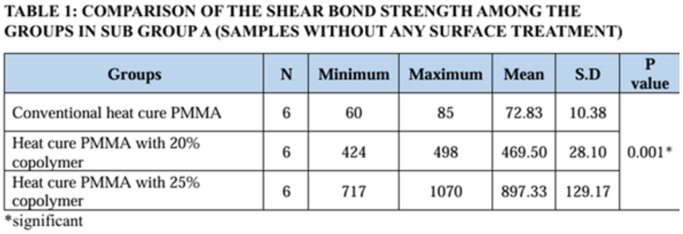


TABLE 1: COMPARISON OF THE SHEAR BOND STRENGTH AMONG THE GROUPS IN SUB GROUP A (SAMPLES WITHOUT ANY SURFACE TREATMENT)

Groups	N	Minimum	Maximum	Mean	S.D	P value
Conventional heat cure PMMA	6	60	85	72.83	10.38	0.001*
Heat cure PMMA with 20% copolymer	6	424	498	469.50	28.10	
Heat cure PMMA with 25% copolymer	6	717	1070	897.33	129.17	

*significant

Graph 1:

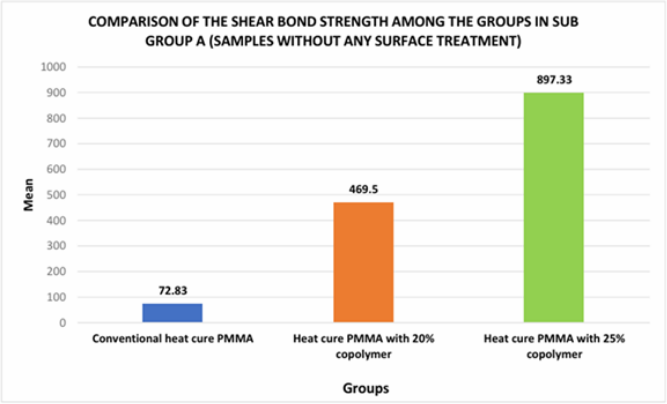


Table 1 presents a comparison of shear bond strength among three groups in Sub Group A, which includes samples without any surface treatment. The conventional heat cure PMMA group exhibited the lowest mean shear bond strength (72.83 ± 10.38 MPa), with values ranging from 60 to 85 MPa. In contrast, the heat cure PMMA with 20% copolymer group showed a markedly higher mean bond strength of 469.50 ± 28.10 MPa, ranging from 424 to 498 MPa. The highest bond strength was observed in the heat cure PMMA with 25% copolymer group, with a mean value of 897.33 ± 129.17 MPa and a range of 717 to 1070 MPa. Statistical analysis revealed a highly significant difference among the groups (P = 0.001), indicating that the addition of copolymer substantially enhances the shear bond strength of heat cure PMMA, even in the absence of surface treatment.

Table 2:

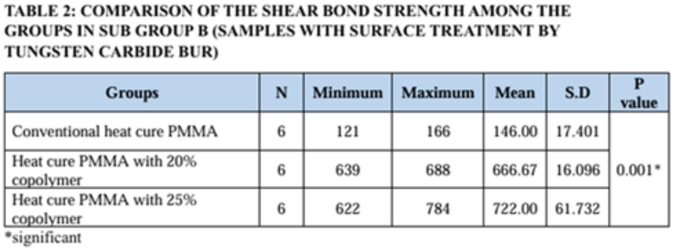


TABLE 2: COMPARISON OF THE SHEAR BOND STRENGTH AMONG THE GROUPS IN SUB GROUP B (SAMPLES WITH SURFACE TREATMENT BY TUNGSTEN CARBIDE BUR)

Groups	N	Minimum	Maximum	Mean	S.D	P value
Conventional heat cure PMMA	6	121	166	146.00	17.401	0.001*
Heat cure PMMA with 20% copolymer	6	639	688	666.67	16.096	
Heat cure PMMA with 25% copolymer	6	622	784	722.00	61.732	

*significant

Graph 2:

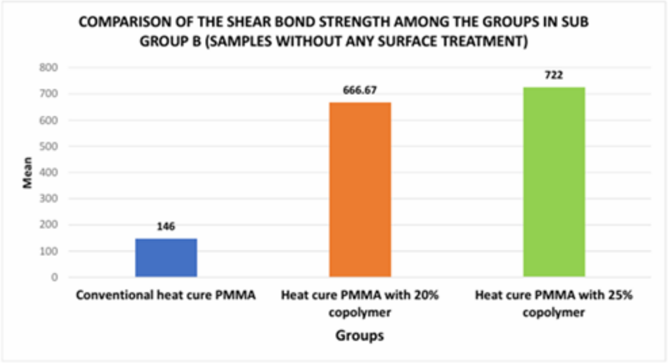


Table 2 compares the shear bond strength among three groups in Sub Group B, which includes samples that underwent surface treatment using a tungsten carbide bur. The conventional heat cure PMMA group exhibited the lowest mean shear bond strength (146.00 ± 17.40 MPa), with a range from 121 to 166 MPa. A substantial increase in bond strength was observed in the heat cure PMMA with 20% copolymer group, which had a mean value of 666.67 ± 16.10 MPa (range: 639 to 688 MPa). Similarly, the heat cure PMMA with 25% copolymer group showed a further increase in strength, with a mean of 722.00 ± 61.73 MPa and values ranging from 622 to 784 MPa. The differences among the groups were statistically significant (P = 0.001), indicating that both the incorporation of copolymer and surface treatment significantly enhance the shear bond strength of heat cure PMMA materials.

Table 3:

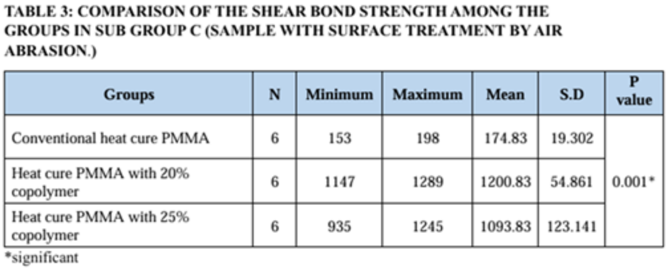


TABLE 3: COMPARISON OF THE SHEAR BOND STRENGTH AMONG THE GROUPS IN SUB GROUP C (SAMPLE WITH SURFACE TREATMENT BY AIR ABRASION.)

Groups	N	Minimum	Maximum	Mean	S.D	P value
Conventional heat cure PMMA	6	153	198	174.83	19.302	0.001*
Heat cure PMMA with 20% copolymer	6	1147	1289	1200.83	54.861	
Heat cure PMMA with 25% copolymer	6	935	1245	1093.83	123.141	

*significant

Graph 3:

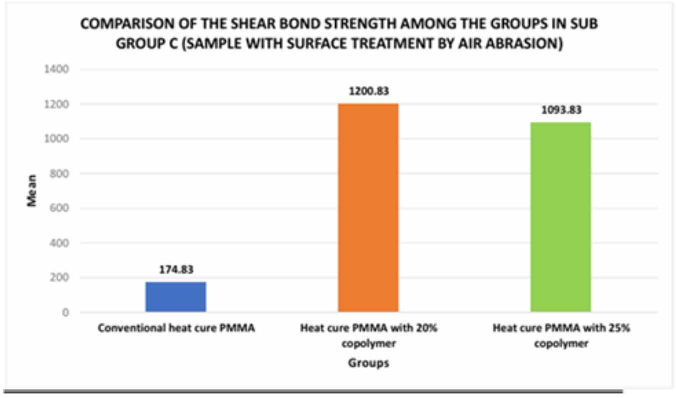


Table 3 presents the comparison of shear bond strength among three groups in Sub Group C, where samples underwent surface treatment via air abrasion. The conventional heat cure PMMA group showed the lowest mean shear bond strength of 174.83 ± 19.30 MPa, with values ranging from 153 to 198 MPa. In contrast, the heat cure PMMA with 20% copolymer group demonstrated a markedly higher mean bond strength of 1200.83 ± 54.86 MPa (range: 1147 to 1289 MPa), while the heat cure PMMA with 25% copolymer group also showed significantly elevated bond strength, with a mean of 1093.83 ± 123.14 MPa and a range of 935 to 1245 MPa. The statistical analysis revealed a significant difference among the groups (P = 0.001), suggesting that surface treatment by air abrasion, especially when combined with copolymer addition, leads to a substantial enhancement in shear bond strength.

Table 4:

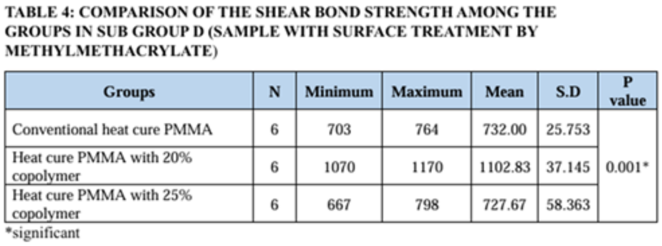


TABLE 4: COMPARISON OF THE SHEAR BOND STRENGTH AMONG THE GROUPS IN SUB GROUP D (SAMPLE WITH SURFACE TREATMENT BY METHYLMETHACRYLATE)

Groups	N	Minimum	Maximum	Mean	S.D	P value
Conventional heat cure PMMA	6	703	764	732.00	25.753	0.001*
Heat cure PMMA with 20% copolymer	6	1070	1170	1102.83	37.145	
Heat cure PMMA with 25% copolymer	6	667	798	727.67	58.363	

*significant

Table 4 shows the comparison of shear bond strength among three groups in Sub Group D, where samples were treated with methy lmethacrylate. The conventional heat cure PMMA group exhibited a mean bond strength of 732.00 ± 25.75 MPa, with values ranging from 703 to 764 MPa. The heat cure PMMA with 20% copolymer group demonstrated the highest bond strength in this subgroup, with a mean of 1102.83 ± 37.15 MPa and a range of 1070 to 1170 MPa. Interestingly, the heat cure PMMA with 25% copolymer group showed a lower mean bond strength (727.67 ± 58.36 MPa; range: 667 to 798 MPa), comparable to the conventional group. The differences among the groups were statistically significant (P = 0.001), indicating that methyl methacrylate surface treatment enhances bond strength, particularly when combined with 20% copolymer, while the 25% copolymer group showed no additional benefit in this context.

Graph 4:

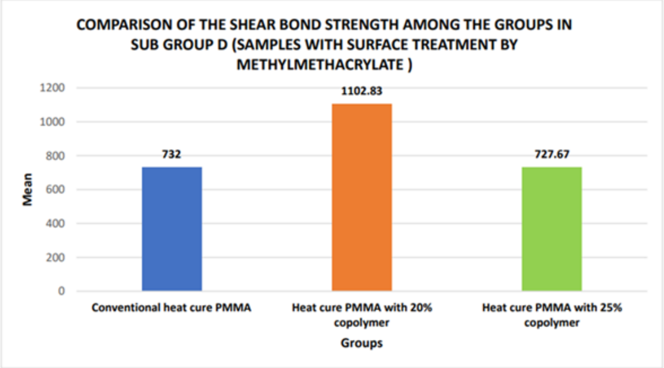


Table 5:

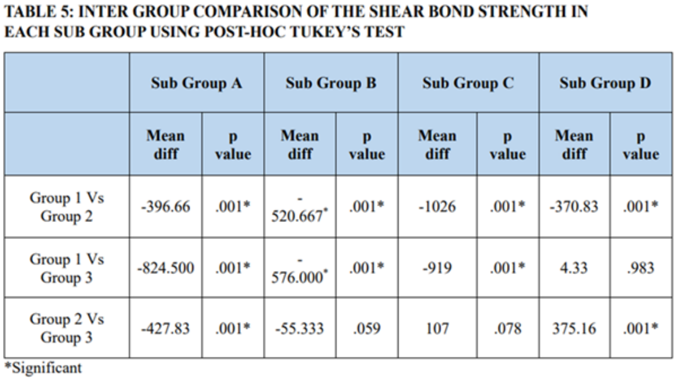


TABLE 5: INTER GROUP COMPARISON OF THE SHEAR BOND STRENGTH IN EACH SUB GROUP USING POST-HOC TUKEY'S TEST

	Sub Group A		Sub Group B		Sub Group C		Sub Group D	
	Mean diff	p value	Mean diff	p value	Mean diff	p value	Mean diff	p value
Group 1 Vs Group 2	-396.66	.001*	-520.667*	.001*	-1026	.001*	-370.83	.001*
Group 1 Vs Group 3	-824.500	.001*	-576.000*	.001*	-919	.001*	4.33	.983
Group 2 Vs Group 3	-427.83	.001*	-55.333	.059	107	.078	375.16	.001*

*Significant

Table 5 presents the inter-group comparison of shear bond strength within each sub group using post-hoc Tukey's test. In Sub Group A (no surface treatment), all comparisons were statistically significant. Group 2 (20% copolymer) and Group 3 (25% copolymer) showed significantly higher bond strength than Group 1 (conventional PMMA), with mean differences of –396.66 MPa and –824.50 MPa respectively (P = 0.001). Additionally, Group 3 also showed significantly higher strength than Group 2 (–427.83 MPa, P = 0.001). In Sub Group B (tungsten carbide bur treatment), Group 2 and Group 3 both had significantly higher bond strength compared to Group 1, with mean differences of –520.67 MPa and –576.00 MPa respectively (P = 0.001). However, the difference between Group 2 and Group 3 was not statistically significant (P = 0.059). In Sub Group C (air abrasion), both Group 2 and Group 3 again demonstrated significantly higher bond strength than Group 1 (–1026 MPa and –919 MPa respectively, P = 0.001), but the difference between Groups 2 and 3 was not significant (P = 0.078), indicating comparable performance. In Sub Group D (methylmethacrylate treatment), Group 2 showed significantly higher strength than both Group 1 and Group 3, with mean differences of –370.83 MPa (P = 0.001) and 375.16 MPa (P = 0.001), respectively. Interestingly, there was no significant difference between Group 1 and Group 3 (mean diff =

4.33, P = 0.983), suggesting that 25% copolymer may not offer added advantage over conventional PMMA in this treatment condition.

Table 6:

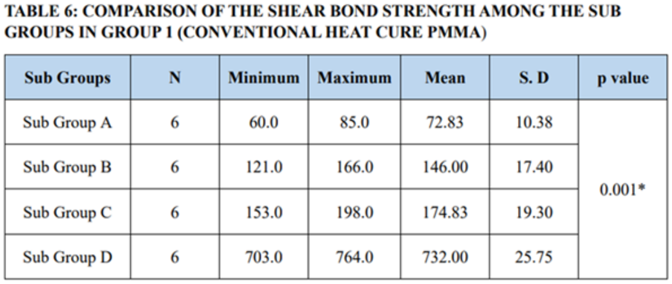


TABLE 6: COMPARISON OF THE SHEAR BOND STRENGTH AMONG THE SUB GROUPS IN GROUP 1 (CONVENTIONAL HEAT CURE PMMA)

Sub Groups	N	Minimum	Maximum	Mean	S. D	p value
Sub Group A	6	60.0	85.0	72.83	10.38	0.001*
Sub Group B	6	121.0	166.0	146.00	17.40	
Sub Group C	6	153.0	198.0	174.83	19.30	
Sub Group D	6	703.0	764.0	732.00	25.75	

Table 6 compares the shear bond strength among the four sub groups within Group 1 (conventional heat cure PMMA). Sub Group A, which had no surface treatment, exhibited the lowest mean bond strength of 72.83 ± 10.38 MPa (range: 60.0 to 85.0 MPa). Bond strength increased progressively with surface treatment: Sub Group B (tungsten carbide bur) had a mean of 146.00 ± 17.40 MPa, and Sub Group C (air abrasion) showed a further increase to 174.83 ± 19.30 MPa. The highest bond strength was observed in Sub Group D (methyl methacrylate treatment), with a mean of 732.00 ± 25.75 MPa, ranging from 703.0 to 764.0 MPa. The differences among the sub groups were statistically significant (P = 0.001), indicating that surface treatment, particularly with methyl methacrylate, significantly enhances the shear bond strength of conventional heat cure PMMA.

Graph 5:

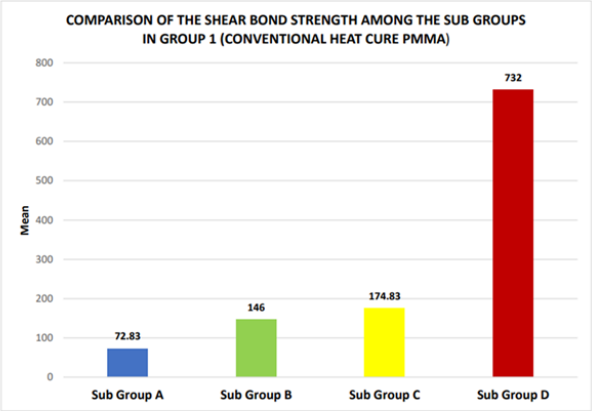


Table 7:

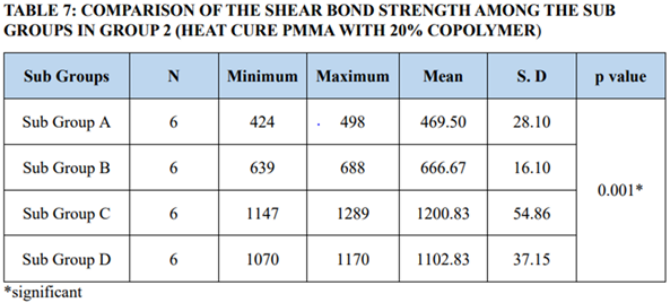


TABLE 7: COMPARISON OF THE SHEAR BOND STRENGTH AMONG THE SUB GROUPS IN GROUP 2 (HEAT CURE PMMA WITH 20% COPOLYMER)

Sub Groups	N	Minimum	Maximum	Mean	S. D	p value
Sub Group A	6	424	498	469.50	28.10	0.001*
Sub Group B	6	639	688	666.67	16.10	
Sub Group C	6	1147	1289	1200.83	54.86	
Sub Group D	6	1070	1170	1102.83	37.15	

*significant

Table 7 presents the comparison of shear bond strength across the four sub groups within Group 2 (heat cure PMMA with 20% copolymer). The lowest bond strength was recorded in Sub Group A (no surface treatment), with a mean of 469.50 ± 28.10 MPa. A notable increase was observed with surface treatments: Sub Group B (tungsten carbide bur) showed a mean of 666.67 ± 16.10 MPa, and Sub Group D (methyl methacrylate) demonstrated a further rise to 1102.83 ± 37.15 MPa. The highest bond strength was achieved in Sub Group C (air abrasion), with a mean of 1200.83 ± 54.86 MPa. The differences among the sub groups were statistically significant (P = 0.001), indicating that surface treatments significantly improve shear bond strength in 20% copolymer-modified PMMA, with air abrasion being the most effective method.

Graph 6:

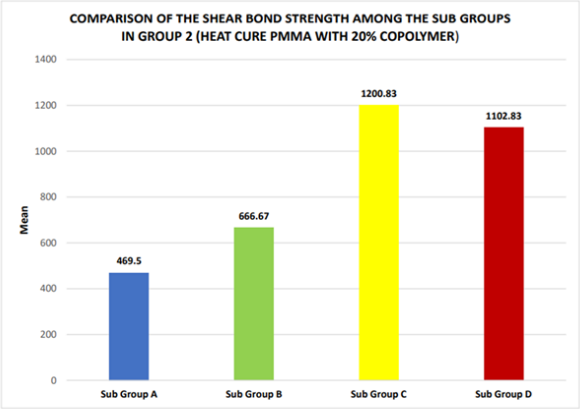


Table 8:

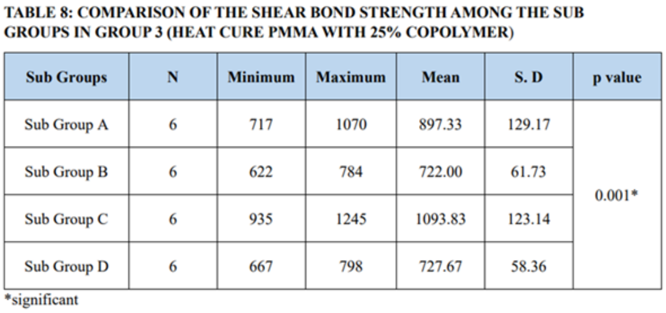


TABLE 8: COMPARISON OF THE SHEAR BOND STRENGTH AMONG THE SUB GROUPS IN GROUP 3 (HEAT CURE PMMA WITH 25% COPOLYMER)

Sub Groups	N	Minimum	Maximum	Mean	S. D	p value
Sub Group A	6	717	1070	897.33	129.17	0.001*
Sub Group B	6	622	784	722.00	61.73	
Sub Group C	6	935	1245	1093.83	123.14	
Sub Group D	6	667	798	727.67	58.36	

*significant

Table 8 shows the comparison of shear bond strength among the four sub groups within Group 3 (heat cure PMMA with 25% copolymer). Sub Group C (air abrasion) exhibited the highest mean bond strength at 1093.83 ± 123.14 MPa (range: 935 to 1245 MPa). The differences among the sub groups were statistically significant (P = 0.001), suggesting that in the case of 25% copolymer-modified PMMA, air abrasion is the most effective surface treatment for enhancing shear bond strength, while other treatments offer comparatively less benefit.

Graph 7:

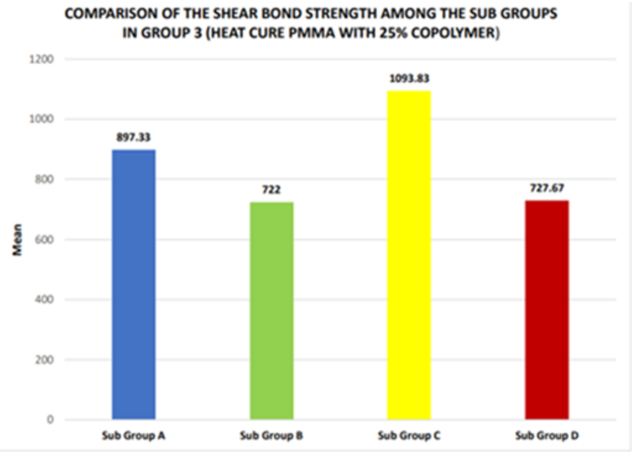


Table 9:

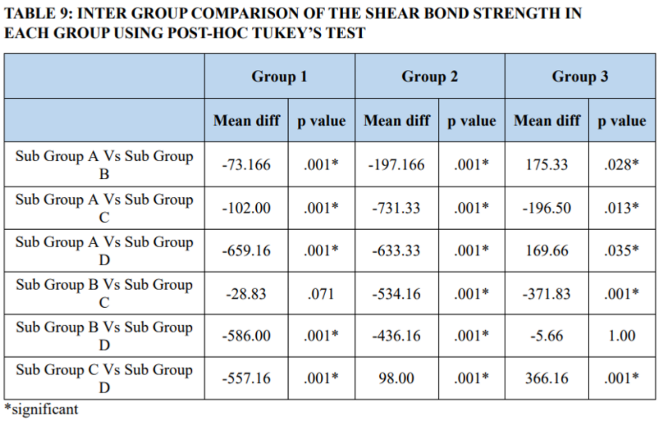


TABLE 9: INTER GROUP COMPARISON OF THE SHEAR BOND STRENGTH IN EACH GROUP USING POST-HOC TUKEY'S TEST

	Group 1		Group 2		Group 3	
	Mean diff	p value	Mean diff	p value	Mean diff	p value
Sub Group A Vs Sub Group B	-73.166	.001*	-197.166	.001*	175.33	.028*
Sub Group A Vs Sub Group C	-102.00	.001*	-731.33	.001*	-196.50	.013*
Sub Group A Vs Sub Group D	-659.16	.001*	-633.33	.001*	169.66	.035*
Sub Group B Vs Sub Group C	-28.83	.071	-534.16	.001*	-371.83	.001*
Sub Group B Vs Sub Group D	-586.00	.001*	-436.16	.001*	-5.66	1.00
Sub Group C Vs Sub Group D	-557.16	.001*	98.00	.001*	366.16	.001*

*significant

Table 9 provides an inter-group comparison of shear bond strength across the different sub groups (A–D) within each main group (Groups 1 to 3), using post-hoc Tukey's test.

In Group 1 (conventional PMMA), all sub-group comparisons were statistically significant. Sub Group D (methyl methacrylate) showed the highest bond strength and differed significantly from Sub Groups A (no treatment), B (tungsten carbide bur), and C (air abrasion), with mean differences of –659.16 MPa, –586.00 MPa, and –557.16 MPa respectively (all P = 0.001).

In Group 2 (PMMA with 20% copolymer), all differences were also significant. Sub Group C (air abrasion) had significantly higher bond strength compared to all others, with the largest mean differences observed vs Sub Group A (–731.33 MPa) and Sub Group B (–534.16 MPa). Sub Group D also showed significantly higher strength than Sub Group A and B (P = 0.001), but was significantly lower than Sub Group C (P = 0.001).

In Group 3 (PMMA with 25% copolymer), Sub Group C again showed the highest strength. Significant differences were found in comparisons such as Sub Group C vs Sub Group B (– 371.83 MPa, P = 0.001) and Sub Group C vs Sub Group D (366.16 MPa, P = 0.001). Interestingly, Sub

Group A had significantly higher strength than both Sub Group B and D.

Discussion

Air abrasion resulted in severe irregularities and undercuts on the bond surface in scanning electron micrographs, and in accordance with the present study, it was effective for strengthening the bond between denture tooth and denture base resin. MMA monomer priming is another attempt that has been made by researchers to enhance bond strength between acrylic resin teeth and denture base materials. It was thought that monomer priming dissolved part of the PMMA of the tooth and enabled free double bonds that might copolymerize with the PMMA of the denture base resin. Nevertheless, it was also exhibited that monomer dissolved the surface of the tooth and provided a durable secondary semi-IPN structure. Therefore, in agreement with the present study, most of the researchers demonstrated that monomer priming to the ridge lap area of tooth surface before packing the resin significantly improved bond strength.[1]

In the present study, roughening the ridge lap surface of the acrylic tooth with tungsten carbide bur improved the bond strength to an extent as compared to unmodified surface similar to studies conducted by Can and Kansu et al and Valittu et al. In the present study, the specimens treated with air abrasion showed comparatively better bond strength.

Intraoral temperature fluctuations are the resultant of routine eating, drinking, and breathing, and can change the interface between the acrylic resin teeth and acrylic resin denture base. Laboratory mimicking of in vivo service is often executed because clinical trials are costly and time-consuming.[1] Oral cavity is subjected to variant temperatures ranging between 4 and 60°C normally and usually simulated in the in vitro researches by the thermal cycling process. Simply, thermal cycling represents mechanical fatigue in a moist oral condition. This study was conducted to evaluate the effect of variant surface treatments and thermal cycling on SBS between repaired artificial acrylic teeth and PMMA denture base resins. [5]

Shear bond strength test was used for this study due to the ease of specimen preparation and simplicity of the test protocol. Also, SBS tests more closely simulate the clinical situation compared to tensile bond strength tests.[6]

A recently identified cycloaliphatic cross-linking comonomer, tricyclodecane dimethanol diacrylate (TCDDMDA) (Sigma Aldrich), has been copolymerized with P(MMA) and experimented as a comonomer with methyl methacrylate (MMA) to investigate the histocompatibility of TCDDMDA comonomer in polymerized resin at 10% and 20% (vol/vol) concentrations in rats by histomorphometric analysis using palatal appliances and they showed good histocompatibility in rats up to 20% (vol/vol) concentration.[7]

This novel copolymer also P(MMA-Co-TCDDMDA) exhibited better mechanical properties and biocompatibility than the conventional P(MMA). Ajay et al has concluded that the addition of cycloaliphatic comonomer increased the SBS between the resultant novel copolymer and the resin teeth after cyclic loading and thermal aging.[1] Surface roughness has also been found to be minimal for this resin by Ajay et al; and therefore microbial adherence and colonization is negligible on the denture surface.[8] However, there is no literature concerning the bond strength of P(MMA-Co-TCDDMDA) copolymeric resin base to artificial teeth after various surface treatments. Hence, the present study evaluated the shear bond strength (SBS) between acrylic denture tooth and P(MMA-Co-TCDDMDA) copolymer after thermal aging.

The limitations of this study include the study being done in vitro which does not completely resemble the oral environment. Many important clinical factors including denture shape and dimension, masticatory forces, and saliva moisturization were not included in this study which might affect the results. Further investigations are needed in vivo or/and in better clinical representation of the in vivo situation like further aging processes or more than 5,000 thermal cycles and different bonding agents.[1]

Conclusion

Within the limitations of the present study, it can be concluded that, PMMA modified with 20% copolymer and 25% copolymer, surface treatment of teeth with air abrasion showed significantly higher bond strength. Therefore, this research supports the potential clinical adoption of cycloaliphatic cross linkers like TCDDMDA in denture base resins along with surface treatment of teeth with air abrasion to improve long-term prosthesis performance, especially in high stress applications such as implant-supported hybrid dentures.

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