

Research Article

Comparison Shear bond strength of stainless still brackets with Primer curing separately versus Co-curing Using seven and eight generation: An In Vitro Study

¹Amanj Rashid Ibrahim*, ²Bayan Abdulla Hassan**

¹BDS, MSc, Orthodontic Trainee at KCHMS, Erbil, Kurdistan Region of Iraq,

²BDS, PhD in Orthodontic, Assistant Professor at College of Dentistry, Erbil, Kurdistan Region of Iraq.

Corresponding Author

Amanj Rashid Ibrahim

Email: amanj.ibrahim@gmail.com

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Abstract: Background: For treatment to be successful, orthodontic brackets must be bonded reliably. The shear bond strength of brackets glued to enamel may be affected by the primer curing method and adhesive composition. This study compared the shear bond strength of orthodontic brackets made of stainless steel that were bonded using adhesive technologies of the seventh and eighth generations, either with separate primer curing or co-curing. **Methods:** This in vitro experimental study was conducted at the laboratory of College of Dentistry, Hawler Medical University, Erbil, Kurdistan Region of Iraq. The study duration was from February 2026 until August 2026 included 100 specimens divided into four groups of 25 according to adhesive generation and curing technique. Shear bond strength was measured in megapascals (MPa). **Results:** The mean shear bond strength was 16.93 ± 4.15 MPa for seventh-generation co-curing, 19.84 ± 5.16 MPa for seventh-generation separate curing, 15.75 ± 5.16 MPa for eighth-generation co-curing, and 16.08 ± 2.99 MPa for eighth-generation separate curing. Seventh-generation adhesives had an overall mean benefit of 2.47 MPa (95% CI: 0.70–4.24), with adhesive generation having a significant influence ($p = 0.007$). The interaction ($p = 0.150$) and the curing method ($p = 0.072$) were not significant. Compared to eighth-generation co-curing ($p = 0.009$) and separate curing ($p = 0.018$), seventh-generation separate curing yielded noticeably greater strength. An overall group difference was also found by the Kruskal-Wallis's test ($p = 0.005$). **Conclusion:** Seventh-generation adhesives outperformed eighth-generation adhesives in terms of overall shear bond strength under laboratory testing. Overall, there was no statistically significant benefit to separate primer curing vs co-curing.

Keywords: Orthodontic brackets; stainless steel; shear bond strength; adhesive systems; primer curing; co-curing.

INTRODUCTION

For orthodontic brackets to remain stable during treatment, they must be bonded to enamel reliably. The adhesive interface must allow bracket removal with the least amount of enamel surface damage while withstanding orthodontic and masticatory stresses. While excessive adhesion may raise the risk of enamel injury during debonding, insufficient bond strength may result in bracket failure, extra sessions, and longer treatment. As a result, bracket retention and enamel preservation must be taken into account when choosing an adhesive method and bonding procedure.^{1,2}

Adhesive dental advancements have aimed to enhance bonding performance, lessen method sensitivity, and streamline clinical operations. Compared to traditional

etch-and-rinse systems, seventh-generation adhesives reduce the number of application stages by combining etching, priming, and bonding components into a single self-etch formulation. The capacity of these techniques to maintain sufficient bracket retention without affecting the quantity of adhesive left on enamel following debonding has been studied.^{3,4} In order to enhance adhesive qualities, more modern universal adhesives often referred to as eighth-generation systems—include functional monomers and, in certain formulations, nanoscale fillers. Functional monomers can support micromechanical retention by facilitating chemical interactions with enamel's mineral component. However, direct comparisons of adhesive systems are required since bonding effectiveness varies depending on the formulation, application methodology, and testing conditions.^{5,6}

The integrity of the enamel-adhesive contact may be affected by primer curing procedure in addition to adhesive composition. The primer can be co-cured with the adhesive after the bracket is positioned, or it can be polymerized independently before the bracket and adhesive resin are placed. While co-curing removes an extra irradiation step and may speed up the bonding process, separate curing creates a polymerized primer layer prior to applying the top resin. These methods have been studied in the past, however depending on the adhesive system employed, their impact on shear bond strength may vary (Tutika et al., 2020; Vattaparambil et al., 2022; Gupta et al., 2024).7-9

Because the opaque bracket base prevents direct light transmission to the underlying resin, adequate photopolymerization is especially important when bonding stainless steel brackets. Therefore, the direction of the irradiation, the length of the exposure, the intensity of the light, and the characteristics of the adhesive material all affect polymerization. The mechanical stability of the bonded interface and resin conversion may be impacted by changes in these variables. Simplified bonding and co-curing procedures can produce satisfactory laboratory bond strengths, but their effectiveness needs to be assessed under uniform circumstances.10,11

The location and features of bond failure should be taken into account when evaluating orthodontic adhesives. Information about the failure interface and the subsequent necessity for adhesive removal can be obtained from the amount of adhesive left on enamel following bracket removal. Although laboratory results cannot accurately replicate the intricate mechanical and environmental circumstances of clinical treatment, these findings supplement shear bond strength data for assessing bonding techniques.3,7

It is still unclear how much primer curing process influences adhesive systems of the seventh and eighth generations. Their reaction to separate curing and co-curing may be influenced by variations in their chemical makeup and polymerization behavior. In order to compare the shear bond strength and debonding properties of stainless-steel orthodontic brackets bonded utilizing seventh- and eighth-generation adhesive systems with independently cured or co-cured primers, an in vitro investigation was conducted. The null hypothesis stated that shear bond strength and adhesive failure patterns would not be appreciably impacted by primer curing methods or adhesive production.

MATERIALS AND METHODS

Study design and setting

This in vitro experimental study evaluated the shear bond strength of stainless-steel orthodontic brackets bonded using seventh- and eighth-generation adhesive systems with two curing protocols: co-curing and separate curing. The study was conducted from February 2026 until August 2026 at the laboratory of the College of Dentistry, Hawler Medical University, Erbil, Iraq.

Ethical considerations

The study proposal was approved by the Kurdistan Higher Council for Medical Specialties. Human teeth were obtained following extraction for clinical indications. Written informed consent for the use of the extracted teeth was obtained from patients after a detailed explanation of the study aim.

Sample selection

The study included 100 extracted human maxillary and mandibular premolars, comprising 25 specimens in each group. The eligibility criteria of the Teeth if they were free from dental caries and fractures and had not previously been treated with formalin, alcohol, hydrogen peroxide, or other bleaching agents all assessed with the naked eye.

Specimen preparation

Following extraction, the teeth were rinsed with normal saline to remove residual soft tissue and surface deposits. The teeth were stored in normal saline at room temperature for six months before testing, with the solution replaced every seven days. No additional disinfection procedure was performed.

Each tooth was embedded in self-curing acrylic resin, with the buccal surface positioned parallel to the loading direction. Before bonding, the buccal enamel surface was polished using a rubber cup and fluoride-free pumice for 10 seconds, rinsed for 10 seconds, and air-dried.

Study groups and bonding materials

The specimens were assigned by manual randomization to four groups, each containing 25 teeth:

1. **Seventh-generation co-curing group (white):** PALFIQUE BOND was applied without independent light-curing before bracket placement. Light-curing was performed after placement of the bracket and adhesive resin.
2. **Seventh-generation separate-curing group (pink):** PALFIQUE BOND was independently light-cured before bracket placement, followed by light-curing of the bracket adhesive resin.
3. **Eighth-generation co-curing group (yellow):** Tokuyama Universal Bond was applied without independent light exposure before bracket placement. Light-curing was performed after placement of the bracket and adhesive resin.
4. **Eighth-generation separate-curing group (red):** Tokuyama Universal Bond received

independent light exposure before bracket placement, followed by light-curing of the bracket adhesive resin.

PALFIQUE BOND (Tokuyama Dental Corporation, Japan), a light-cured self-etching bonding method, was the seventh generation of adhesive. Tokuyama Universal Bond (Tokuyama Dental Corporation, Japan), a two-component, self-curing universal glue, was the eighth generation of adhesive. The experimental light-exposure sequences employed in this investigation were referred to as co-curing and separate curing. All groups used Ortho Link orthodontic adhesive resin (Orthometric, Brazil).

Orthodontic bonding procedure

Discovery Smart stainless-steel brackets (Dentaurum, Germany), designed for tooth 24, were used. The brackets had a slot size of 0.022×0.030 inches, a torque of -7° , and an angulation of 0° . The bracket base area was 9.63 mm^2 , and bonding area 10.56 mm^2 according to the manufacturer's specifications.

The same enamel-conditioning procedure was used for all the groups. The buccal enamel surface was etched for 20 seconds with 37% phosphoric acid, then rinsed for 10 seconds, and then air-dried for 10 seconds. The assigned adhesive was then applied for 5 seconds.

In the separate-curing groups, the adhesive layer received light exposure for 20 seconds before bracket placement. In the co-curing groups, no independent light exposure was performed before bracket placement. Ortho Link adhesive resin was applied to the bracket base, and the bracket was positioned using an adjustable dental bracket gauge (Morelli, Brazil). Excess resin was removed using a dental probe.

Following bracket placement, light-curing was performed for 10 seconds in the co-curing groups and 20 seconds in the separate-curing groups. An Apple C25 Plus light-curing unit was used at an irradiance of $2,500 \text{ mW/cm}^2$. All bonding procedures were performed by one operator.

Post-bonding storage

Before undergoing mechanical testing, the specimens were kept in regular saline after bonding.

RESULTS

Shear bond strength measurement

Shear bond strength was measured using a universal testing machine (Laryee, model UE2420, China). A flattened steel rod was positioned at the bracket-tooth interface, and loading was applied parallel to the facial surface of the tooth at a crosshead speed of 1 mm/min until bracket debonding occurred.

Newtons were used to measure the highest force at debonding. The debonding force was divided by the bracket base area to determine the shear bond strength:

$$\text{Shear bond strength (MPa)} = \text{Debonding force (N)} \div \text{Bracket base area (mm}^2\text{)}$$

Mechanical testing was performed by an operator blinded to group allocation. The primary outcome was shear bond strength, expressed in megapascals.

Statistical analysis

SPSS version 26 was used to conduct statistical analyzes. Means and standard deviations, 95% confidence intervals for the means, medians, first and third quartiles, and minimum and maximum values were used to summarize shear bond strength.

The effects of adhesive generation, curing method, and their combination on shear bond strength were investigated using a two-way analysis of variance (ANOVA). The effect size was reported using partial eta squared. The ANOVA model was used to assess overall mean differences between adhesive generations and curing methods with 95% confidence intervals. Tukey's technique was used to do pairwise comparisons between the four groups, adjusting for each of the six comparisons. Levene's test was used to determine equality of variances, and the Shapiro-Wilk test was used to determine whether the ANOVA residuals were normal. A Kruskal-Wallis test was also carried out as a nonparametric sensitivity analysis of the total difference between the four groups since residuals deviated from normality. The analysis included all 100 reported measurements. The threshold for statistical significance was set at $p < 0.05$.

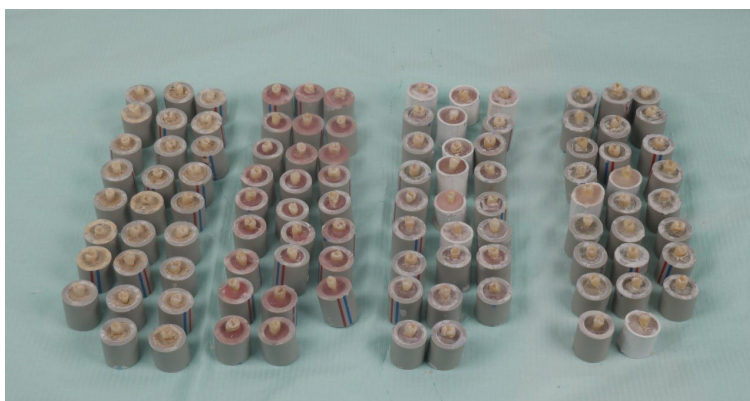


Figure (1): Extracted premolars mounted in cylindrical blocks and arranged into four experimental groups.



Figure (2): Setup for measuring the shear bond strength of orthodontic brackets bonded to extracted premolars.

Table (1) presents the descriptive statistics of shear bond strength for the four groups. Seventh-generation adhesives with co-curing had a mean strength of 16.93 ± 4.15 MPa, a 95% confidence interval (CI) of 15.21–18.64 MPa, a median of 15.60 MPa (Q1–Q3: 14.70–18.70), and a range of 9.30–25.70 MPa. Seventh-generation adhesives with separate curing had a mean of 19.84 ± 5.16 MPa, a 95% CI of 17.71–21.97 MPa, a median of 19.50 MPa (Q1–Q3: 16.50–21.00), and a range of 12.10–36.60 MPa. Eighth-generation adhesives with co-curing had a mean of 15.75 ± 5.16 MPa, a 95% CI of 13.62–17.88 MPa, a median of 15.60 MPa (Q1–Q3: 13.20–18.40), and a range of 6.10–28.20 MPa. Eighth-generation adhesives with separate curing had a mean of 16.08 ± 2.99 MPa, a 95% CI of 14.84–17.31 MPa, a median of 15.70 MPa (Q1–Q3: 13.90–18.40), and a range of 10.60–22.60 MPa.

Table (1): Descriptive statistics of shear bond strength according to adhesive generation and curing technique

Adhesive generation	Curing technique	Mean $\pm$ SD (MPa)	95% CI for mean (MPa)	Median (Q1–Q3) (MPa)	Minimum–maximum (MPa)
Seventh	Co-curing	16.93 ± 4.15	15.21–18.64	15.60 (14.70–18.70)	9.30–25.70
Seventh	Separate curing	19.84 ± 5.16	17.71–21.97	19.50 (16.50–21.00)	12.10–36.60
Eighth	Co-curing	15.75 ± 5.16	13.62–17.88	15.60 (13.20–18.40)	6.10–28.20
Eighth	Separate curing	16.08 ± 2.99	14.84–17.31	15.70 (13.90–18.40)	10.60–22.60

Table (2) presents the two-way ANOVA results. Adhesive generation had a sum of squares of 152.52, one degree of freedom, a mean square of 152.52, an F-value of 7.685, a p-value of 0.007, and a partial η^2 of 0.074. Curing technique had a sum of squares of 65.45, one degree of freedom, a mean square of 65.45, an F-value of 3.298, a p-value of 0.072, and a partial η^2 of 0.033. The interaction between adhesive generation and curing technique had a sum of squares of 41.86, one degree of freedom, a mean square of 41.86, an F-value of 2.109, a p-value of 0.150, and a partial η^2 of 0.021. The error sum of squares was 1,905.24, with 96 degrees of freedom and a mean square of 19.85. The corrected total sum of squares was 2,165.07, with 99 degrees of freedom.

Table (2): Two-way ANOVA examining the effects of adhesive generation and curing technique on shear bond strength

Source of variation	Sum of squares	df	Mean square	F	p-value	Partial η^2
Adhesive generation	152.52	1	152.52	7.685	0.007	0.074
Curing technique	65.45	1	65.45	3.298	0.072	0.033
Generation $\times$ curing technique	41.86	1	41.86	2.109	0.150	0.021
Error	1,905.24	96	19.85	—	—	—
Corrected total	2,165.07	99	—	—	—	—

Table (3) reports the overall mean differences in shear bond strength. The mean difference between seventh- and eighth-generation adhesives, averaged across curing techniques, was 2.47 MPa (95% CI: 0.70–4.24; $p = 0.007$). The mean difference between separate curing and co-curing, averaged across adhesive generations, was 1.62 MPa (95% CI: –0.15–3.39; $p = 0.072$).

Table (3): Overall differences in shear bond strength by adhesive generation and curing technique

Comparison	Mean difference (MPa)	95% CI (MPa)	p-value
Seventh versus eighth generation, averaged across curing techniques	2.47	0.70–4.24	0.007
Separate curing versus co-curing, averaged across generations	1.62	–0.15–3.39	0.072

Table 4 presents the six Tukey-adjusted pairwise comparisons, with mean differences calculated as the first group minus the second group. Seventh-generation co-curing versus seventh-generation separate curing had a mean difference of –2.91 MPa (simultaneous 95% CI: –6.21–0.38; adjusted $p = 0.103$). Seventh-generation co-curing versus eighth-generation co-curing had a mean difference of 1.18 MPa (95% CI: –2.12–4.47; adjusted $p = 0.787$), while seventh-generation co-curing versus eighth-generation separate curing had a mean difference of 0.85 MPa (95% CI: –2.44–4.15; adjusted $p = 0.906$). Seventh-generation separate curing versus eighth-generation co-curing had a mean difference of 4.09 MPa (95% CI: 0.79–7.38; adjusted $p = 0.009$). Seventh-generation separate curing versus eighth-generation separate curing had a mean difference of 3.76 MPa (95% CI: 0.47–7.06; adjusted $p = 0.018$). Eighth-generation co-curing versus eighth-generation separate curing had a mean difference of –0.32 MPa (95% CI: –3.62–2.97; adjusted $p = 0.994$).

Table (4): Tukey-adjusted pairwise comparisons of shear bond strength between the four groups

First group	Second group	Mean difference (MPa)	Simultaneous 95% CI (MPa)	Adjusted p-value
Seventh, co-curing	Seventh, separate curing	–2.91	–6.21–0.38	0.103
Seventh, co-curing	Eighth, co-curing	1.18	–2.12–4.47	0.787
Seventh, co-curing	Eighth, separate curing	0.85	–2.44–4.15	0.906
Seventh, separate curing	Eighth, co-curing	4.09	0.79–7.38	0.009
Seventh, separate curing	Eighth, separate curing	3.76	0.47–7.06	0.018
Eighth, co-curing	Eighth, separate curing	–0.32	–3.62–2.97	0.994

Mean difference = first group minus second group. Tukey adjustment accounts for all six comparisons.

Table (5) presents the assumption checks and nonparametric sensitivity analysis. Levene's test for equality of variances yielded an F-value of 0.976, with 3 and 96 degrees of freedom and a p-value of 0.407. The Shapiro-Wilk test of ANOVA residuals yielded a W-value of 0.944 and a p-value of <0.001. The Kruskal-Wallis comparison of the four groups yielded an H-value of 12.883, with three degrees of freedom and a p-value of 0.005.

Table (5): Assumption checks and nonparametric sensitivity analysis

Analysis	Statistic	df	p-value
Levene's test for equality of variances	F = 0.976	3, 96	0.407
Shapiro-Wilk test of ANOVA residuals	W = 0.944	—	<0.001
Kruskal-Wallis comparison of the four groups	H = 12.883	3	0.005

DISCUSSION

The shear bond strength of adhesives from the seventh and eighth generations employing co-curing and separate curing was compared in this study. The maximum mean strength was found with seventh-generation separate curing (19.84 ± 5.16 MPa), followed by seventh-generation co-curing (16.93 ± 4.15 MPa). Eighth-generation co-curing and separate curing yielded averages of 15.75 ± 5.16 MPa and 16.08 ± 2.99 MPa, respectively. While curing technique ($p = 0.072$) and the interaction between the two components ($p = 0.150$) were not significant, adhesive generation had a significant impact ($p = 0.007$).

Pre-cured and non-pre-cured primers did not significantly vary, according to Oesterle et al.¹² Transbond APC generated averages of 17.60 ± 4.46 MPa without pre-curing and 17.69 ± 5.53 MPa with pre-curing at 30 minutes. This is consistent with our negligible curing effect. Tutika et al., however, found that pre-curing significantly increased strength, measuring 16.77 ± 3.41 MPa as opposed to 11.59 ± 2.21 MPa without pre-curing.⁷ Although our seventh-generation groups displayed the same numerical direction, there was no significant difference between them ($p = 0.103$).

According to Vattaparambil et al., primer pre-curing produced stronger bonds than co-curing. Pre-cured Transbond XT yielded the highest mean of 20.56 ± 3.22 MPa, whereas co-cured Orthofix yielded 7.57 ± 0.49 MPa. Their pre-cured Transbond XT result was nearly identical to our highest mean, 19.84 MPa.⁸ But since these numbers used different adhesives, curing alone cannot account for the discrepancy. Co-curing increased immediate strength ($p < 0.05$), according to Abdelaziz et al., but there were no discernible changes during artificial aging. Their results demonstrate how testing conditions can affect how different curing methods are compared.¹¹

In contrast to our findings, Thota et al. observed greater strength using eighth-generation adhesives. They measured 13.09 ± 0.79 MPa for metal brackets using G-Premio Bond and 11.54 ± 0.91 MPa using the seventh-generation adhesive.⁶ The overall mean advantage of

seventh-generation adhesives in our investigation was 2.47 MPa. This discrepancy could be explained by variations in adhesive formulations and application techniques. These findings imply that, in all experimental circumstances, a higher generation label does not necessarily imply greater strength.

The universal adhesive strengths shown here are significantly higher than those reported by Garg et al. The Single Bond Universal mean was 2.29 ± 1.12 MPa, the Tetric-N-Bond Universal mean was 5.26 ± 2.60 MPa, and the G-Premio Bond mean was 5.07 ± 1.72 MPa. Transbond XT outperformed universal systems, producing 10.22 ± 4.83 MPa.¹³ Similar low baseline values of 3.8 ± 2.0 , 1.9 ± 1.0 , and 4.1 ± 1.4 MPa were reported by Cerone et al. for three universal adhesives applied to uncut enamel.¹⁴ The difference in bonding procedures was evident in our eighth-generation means, which were greater.

The means for Single Bond Universal and G-Premio Bond were 20.57 ± 4.43 MPa and 20.75 ± 5.72 MPa, respectively, according to Eren et al. Compared to our eighth-generation data, these values were higher. 33.50 ± 13.07 MPa was achieved by their Transbond XT group and standard phosphoric acid.¹⁵ Lower enamel strengths of 15.51 ± 3.49 MPa for Transbond XT, 12.09 ± 3.85 MPa for Scotchbond Universal, and 6.96 ± 2.00 MPa for iBond were reported by Hellak et al. When taken as a whole, these experiments demonstrate how different adhesive systems work.¹⁶

After 20,000 thermal cycles, Proença et al. reported mean strengths ranging from 8.9 to 15.8 MPa, with no discernible difference between Transbond Plus SEP and universal adhesives.¹⁷ The range of our means was 15.75 to 19.84 MPa. However, direct comparison is limited because their study used bovine teeth and substantial thermal aging. These variations show how crucial it is to take specimen type and storage circumstances into account when comparing laboratory bond strengths. The limitations of laboratory testing should be taken into consideration when interpreting the current results. The Kruskal-Wallis test revealed an overall group difference ($p = 0.005$), however residuals were not normally

distributed. Stronger bonding cannot be interpreted as proof of safer debonding because adhesive residual scores and enamel damage were not included in the results provided. Clinical bracket retention, failure patterns, and bond durability should all be assessed in future research. Seventh-generation adhesives were generally stronger, but there was no discernible overall benefit to separate curing.

CONCLUSION

The seventh-generation adhesive system outperformed the eighth-generation system in terms of overall shear bond strength under the specified laboratory circumstances. There was no discernible overall difference between separate curing and co-curing, despite the fact that seventh-generation glue with separate primer curing produced the highest mean strength. To evaluate bracket retention and bond durability, more clinical research is required.

Conflict of interest: The authors declare no conflict of interest

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