An Evaluation of Shear Bond Strength of Metal Orthodontic Brackets Bonded with Two Different Adhesives Using A High Intensity Led Curing Unit At Different Curing Times – An in Vitro Study

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ABSTRACT
OBJECTIVES: To evaluate and compare the shear bond strength (SBS) and the residual adhesive left on metal orthodontic brackets bonded with Transbond XT and Bracepaste using a Woodpecker iLED curing unit (2500 mW/cm^2) at different curing times.
METHOD: According to curing time and composite type, ninety extracted human premolar teeth were divided into six groups, compromising 15 teeth per group. Metal brackets were bonded to the teeth with Transbond XT and Bracepaste, wgile the curing durations were at 6 seconds, 3 seconds, and 1 second, correspondingly. SBS was measured with a Hounsfield universal testing machine. Following bracket debonding, the surfaces were examined to assess the adhesive remnant index (ARI).
RESULTS: A significant difference was found in the Shear Bond Strength of Transbond XT and Bracepaste cured for 6 seconds, 3 seconds, and 1 second ($p < 0.001$). Groups cured for 6 seconds exhibited the highest SBS, while those cured for 1 second demonstrated the lowest SBS. Also, a significant difference was noted in the quantity of adhesive left in the Transbond XT group, whereas no statistically significant difference was detected in the amount of adhesive remaining in the Bracepaste group.
CONCLUSION: Shortening the curing duration leads to a reduction in shear bond strength (SBS), irrespective of utilizing a high-intensity LED light-curing device. Adequate SBS was accomplished with Transbond XT when cured for 6, 3, and 1 second, and with Bracepaste when cured for 6 and 3 seconds, employing a high-intensity LED curing light.

KEYWORDS: Shear bond strength, Adhesives, Curing time

1. INTRODUCTION

The bonding procedure in orthodontics has long been considered one of the most time-consuming procedures in orthodontics. Reducing the curing time needed for composite resin hardening would not only improve treatment efficiency but also increase patient comfort [1–4]. Mills proposed the use of light-emitting diode (LED) curing lights as an effective means for polymerizing light-cured composite resins [5]. LED technology offers several benefits, including shorter curing times, stable light intensity output, and reduced heat generation [6–8]. Additionally, LED units emit light at a wavelength of 450–490 nm, which coincides with the absorption peak of camphoroquinone, thereby decreasing curing times and improving bond strength [6,8].

Both the intensity of the curing light and the exposure time are directly related to the degree of polymerization in light-curing adhesives. It has been proposed that shortening the curing time while increasing the light intensity may be equally effective as lengthening the curing duration with lower intensity [9]. Advances in curing technology have enabled the enhancement of light power density, thereby shortening the required exposure time without compromising the bonding efficiency [2].

Reynolds suggested that bond strengths between 5.9–7.8 MPa are sufficient to resist the forces of mastication [10]. Bracket bond failure can lead to longer treatment durations and additional material loss, while excessive bond strength can potentially damage enamel during debonding. Therefore, an ideal adhesive should provide sufficient bond strength throughout the treatment while also protecting the enamel during debonding [4,11,12].

Currently, there are high-intensity LED curing units capable of achieving acceptable bond strengths even when the curing time is reduced [2,6]. Nevertheless, there is a scarcity of research investigating the effects of shorter curing durations on various adhesives when utilizing a high-intensity LED curing unit.

2. METHODOLOGY

The sample size calculated to be 90, consisting of 15 samples in each group. For this research, 90 healthy, non-cavitated human premolar teeth, removed for orthodontic or periodontal purposes, were chosen. The teeth were sterilized with 0.1% thymol solution and cleaned. Once cleaned, they were kept at room temperature within the sealed containers immersed in distilled water to avoid dehydration. The water was altered every week to inhibit bacterial growth. Every tooth was set using a self-cure acrylic block, leaving just the crown visible while the root stayed completely covered in the acrylic. The tooth's facial surface was set at a right angle to the acrylic base. A consistent method was utilized to verify that the bracket base was parallel to the rod applying force during shear bond strength (SBS) testing. The 90 samples were divided into six groups, each group consisting of 15 teeth, and assigned color codes to prevent any confusion (Table 1). The buccal surface of every tooth was treated with a rubber prophylactic cup connected to a low-speed handpiece for 10 seconds, followed by rinsing and drying using a three-way syringe. Following cleaning and polishing, the teeth were etched using 37% phosphoric acid for 30 seconds, rinsed and dried until a chalky white appearance became evident. Light curing was conducted with the Woodpecker iLED light- curing unit (2500 mW/cm²) for each sample, using the appropriate primers applied by the same operator.

Group 1, 2 &3:

The bonding area on the tooth surface was treated with Transbond XT primer and cured for 6 seconds. Premolar Gemini PEA brackets with 0.022-inch slot and MBT prescription were bonded to the center of the buccal surfaces of all the teeth, parallel to the long axis, using Transbond XT adhesive. The brackets were then pressed firmly with enough pressure to remove any excess composite. In groups 1, 2, and 3, the adhesive underwent light-curing for 6 seconds, 3 seconds and 1 second correspondingly (Figure 1).

Group 4, 5 &6:

The bonding area on the tooth surface was treated with Bracepaste MTP primer and cured for 6 seconds. Premolar Gemini PEA brackets with 0.022-inch slot and MBT prescription were bonded to the tooth as described earlier. In groups 4, 5, and 6, the adhesive was light-cured for 6 seconds, 3 seconds, and 1 second, respectively (Figure 1).

During the curing process, care was taken to position the light guide near the tooth without contacting the bracket, as the light intensity diminishes with the square of the distance. Following this, all the specimens were stored in artificial saliva at room temperature for 24 hours to simulate the oral environment.

The shear bond strength was assessed with a Hounsfield universal testing machine, calibrated to a crosshead speed of 0.5 mm/min. Shear force was applied on the occlusal edge of the bracket base with a rectangular rod until it failed. The force was exerted in an occluso-gingival direction, aligned with the junction between the tooth and bracket, until debonding occurred (Figure 2).

The force needed to debond the brackets was measured in kilograms-force and then transformed into megapascals (MPa) by dividing the force in newtons by the bracket base's surface area (1 KgF = 9.806 N, 1 MPa = 1 N/mm^2).

The shear bond strength for each specimen was determined with this formula:

Bond Strength = Breaking Load / Nominal Area of Bonding.

After the bracket was debonded, the surfaces were examined with a magnifying glass to assess the Adhesive Remnant Index (ARI). The ratings, as suggested by Artun and Bergland [13], varied from 0 to 3 and were allocated in this manner:

- 0 = no adhesive left on dental enamel
- 1 = less than half adhesive left on dental enamel
- 2 = more than half adhesive left on dental enamel
- 3 = all adhesive left on dental enamel, including an impression of the bracket mesh.

The ARI score was utilized to identify the location of the bond failure.

3. STATISTICAL ANALYSIS:

SPSS version 16.0 was used to statistically analyze the data. Independent t-test was used to measure the Shear bond strength between the two groups. For comparison among three groups a one-way ANOVA was conducted, followed by a Tukey post-hoc test. The Mann-Whitney test was utilized to compare the adhesive remnant index between two groups, whereas the Kruskal-Wallis test was employed for the comparison among three groups, alongside post-Hoc H statistics.

4. RESULTS

A statistically significant difference was identified between the groups (Table 2, 3).

All groups in both Transbond XT and Bracepaste exhibited statistically significant differences (Tukey's post-hoc $p < 0.001$). An independent t-test was performed for intergroup comparison, showing a statistically significant difference between the groups (Table 4).

Group 1 (Transbond XT cured for 6 seconds) demonstrated the greatest shear bond strength (9.45 MPa), whereas Group 6 (Bracepaste cured for 1 second) displayed the least shear bond strength (4.24

MPa). The shear bond strengths for Groups 2, 3, 4, and 5 were measured at 7.57 MPa, 6.02 MPa, 7.54 MPa, and 6.10 MPa, respectively (Figures 3, 4). The frequency distribution and median of the Adhesive Remnant Index (ARI) for Transbond XT and Bracepaste are shown in (Table 4). Intragroup comparison was conducted utilizing the Kruskal- Wallis test along with post-hoc H statistics. For Transbond XT, noteworthy differences in the ARI scores were noted among all groups (Group 1, Group 2, and Group 3) (p-value = 0.003). Groups 1 and 2 had a median ARI score of 2, whereas Group 3 had a median ARI score of 1 (Figure 5).

Intragroup analysis for Bracepaste showed no statistically significant differences in the ARI scores among all groups (Group 4, Group 5, and Group 6) (p-value = 0.057). Groups 5 and 6 exhibited a median ARI score of 1, while Group 4 displayed a median ARI score of 2. Intergroup comparisons were performed using the Mann-Whitney test, revealing no statistically significant differences in the Adhesive remnant indices for all groups cured for 6, 3, and 1 second, respectively (Table 5).

5. DISCUSSION

Decreasing the curing time with an LED curing light leads to a decrease in shear bond strength, which is consistent with findings from Almeida et al. [1], Dall'Igna et al. [14], Swanson et al. [8], Gronberg et al. [15], Al-Khatieeb et al. [6], and Gomes et al. [2]. As the curing light exposure time is shortened, the degree of conversion in the composite also decreases. A primary objective of orthodontic bonding is to ensure adequate bond strength that is clinically significant, as brackets in the oral cavity are constantly exposed to stresses [17]. Incomplete polymerization of the composite is a key factor contributing to bond failure and reduced bond strength. Reynolds suggests that a bond strength ranging from 5.9 to 7.8 MPa is adequate to withstand masticatory forces under clinical conditions [10].

This in-vitro research assessed the shear bond strength of orthodontic brackets bonded with Transbond XT and Bracepaste, employing a high-intensity LED curing device for curing times of 6, 3, and 1 second. The findings indicated that bond strength reduced with shorter curing times, regardless of the adhesive utilized, even when a powerful LED curing device was used. Numerous studies have indicated a reduction in shear bond strength with shorter curing times, which is often attributed to the decreased degree of monomer-to-polymer conversion. [2,5,6,8,14,15,18,19]

An additional key factor influencing the level of polymerization, is the intensity of the curing light. The higher the power of the LED light-curing unit, the more photons are delivered to the adhesive, increasing the availability of free radicals for the conversion of monomer into polymer, which in turn enhances the shear bond strength [9,16,20]. Similar studies using high-power LED curing lights have reported results consistent with those of the current study. A clinical study by Ward J.D. et al. [18] showed no difference in the bond failure rate when curing time was reduced to 6 seconds with a curing light intensity of 3200 mW/cm². Studies by Almeida et al. [1], Al-Khatieeb et al. [6], and Palomares et al. [5] also support the current study's findings, showing that shear bond strength decreases as curing time is shortened, even with the use of a high-power LED curing light.

When comparing the findings of the current study to the bond strength values from Reynolds' research [10], it was observed that Groups 1, 2, and 3, cured with Transbond XT for 6, 3, and 1 second, demonstrated adequate shear bond strength. In contrast, in the Bracepaste groups, Groups 4 and 5, cured for 6 and 3 seconds, displayed adequate bond strength, while Group 6, cured for 1 second, lacked sufficient bond strength to withstand masticatory forces. This suggests that, even with the use of high-intensity LED curing light, shear bond strength values differ based on the type of adhesive applied. This variation can be attributed to the different chemical compositions of the adhesives, as composites tend to react differently [1,21,22]. Both intra- and intergroup comparisons in the current study yielded statistically significant results.

Higher bond strength values are important to guarantee that the brackets remain attached to the teeth during the entire treatment. Nevertheless, higher bond strengths are linked to a greater likelihood of enamel fracture when debonding occurs. The results of this study showed that Groups 1, 2, and 4 all had an Adhesive Remnant Index (ARI) score of 2. In contrast, Groups 3, 5, and 6 had an ARI score of 1. The duration of light curing notably influenced the quantity of residual adhesive in the Transbond XT group, while this effect was not significant for the Bracepaste group.

The adhesive failure interface between the bracket and the composite is regarded as the safest failure pattern as it prevents enamel fracture during debonding [23]. All the groups in the current study exhibited this safe adhesive failure pattern, which aligns with the findings of other studies [1,6,17,20].

A key concern with increasing the intensity or power of the LED curing unit is the heat generated during the adhesive curing process. Excessive heat could potentially damage the pulp and surrounding tissues, raising significant concerns. There are conflicting findings among researchers regarding heat generation with different LED light-curing units [24–25]. The finding of this research relies on in-vitro lab settings, which do not completely mimic the conditions found in the mouth. As a result, clinical trials are suggested to verify and substantiate the results of this study.

6. CONCLUSION

Taking into account the limitations of this study, the following conclusions can be made:

1. A significant variation in shear bond strength was observed for Transbond XT when cured for 6 seconds, 3 seconds, and 1 second, respectively.
2. Within the Transbond XT groups, the highest shear bond strength was observed in Group 1, cured for 6 seconds, while the lowest was found in Group 3, cured for 1 second.
3. The amount of adhesive remaining on the enamel surface in the Transbond XT group changed significantly with a reduction in light curing time.
4. A significant variation in shear bond strength was observed for Bracepaste when cured for 6 seconds, 3 seconds, and 1 second, respectively.
5. Among the Bracepaste groups, Group 4, cured for 6 seconds, exhibited the highest shear bond strength, while Group 6, cured for 1 second, showed the lowest shear bond strength.
6. The amount of adhesive left on the enamel surface in the Bracepaste group showed no significant change with a decrease in light curing time.
7. Transbond XT cured for 6 sec, 3 sec, 1 sec and Bracepaste cured for 6 sec, 3 sec using a high intensity LED curing light provided sufficient SBS.

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8. TABLES:

Table 1: Description of groups tested

ADHESIVE	GROUPS	CURING TIME	NO OF SAMPLES
TRANSBOND XT adhesive and primer	GROUP 1	6 sec	15
	GROUP 2	3 sec	15
	GROUP 3	1 sec	15
BRACEPASTE® adhesive and primer	GROUP 4	6 sec	15
	GROUP 5	3 sec	15
	GROUP 6	1 sec	15

Table 2: Descriptive data for shear bond strength of Transbond XT

	N	Minimum	Maximum	Mean	SD
Group 1	15	8.12	10.72	9.45	0.82
Group 2	15	6.24	8.82	7.57	0.66
Group 3	15	4.89	7.02	6.02	0.62
F = 89.16		p < 0.001		(Tukey's post Hoc is < 0.001)	

Table 3: Descriptive data for shear bond strength of Bracepaste

	N	Minimum	Maximum	Mean	SD
Group 4	15	6.04	8.59	7.54	0.78

Group 5	15	4.81	7.02	6.10	0.68
Group 6	15	3.12	5.32	4.24	0.66
F = 81.49		p < 0.001		(Tukey's post Hoc is < 0.001)	

Table 4: Intergroup comparison of shear bond strength

Curing Time	Mean (SD)		p-value
	Transbond XT	Bracepaste	
6 seconds	9.45 (0.82)	7.54 (0.78)	<0.001
3 seconds	7.57 (0.66)	6.10 (0.68)	<0.001
1 second	6.02 (0.62)	4.24 (0.66)	<0.001

Table 5: Intergroup comparison of Adhesive remnant index (ARI Score)

Curing Time	Score	Frequency	Transbond Median (IQR)	Score	Frequency	Bracepaste Median (IQR)	p-value
6 seconds	0	0	2.00 (1.00 – 3.00)	0	2 (13.3%)	2.00 (1.00 – 2.00)	U-test statistic = 82.5 p = 0.217
	1	4 (27.7%)		1	5 (33.3%)		
	2	6 (40.0%)		2	5 (33.3%)		
	3	5 (33.3%)		3	3 (20.0%)		
3 seconds	0	0	2.00 (1.00 – 2.00)	0	2 (13.3%)	1.00 (1.00 – 2.00)	U-test statistic = 75.5 p = 0.126
	1	7 (47.7%)		1	8 (53.3%)		
	2	5 (33.3%)		2	5 (33.3%)		
	3	3 (20.0%)		3	0		
1 second	0	3 (20.0%)	1.00 (1.00 – 1.00)	0	6 (40.0%)	1.00 (0 – 1.00)	U-test statistic = 94.5 p = 0.461
	1	9 (60.0%)		1	6 (40.0%)		
	2	3 (20.0%)		2	3 (20.0%)		
	3	0		3	0		

FIGURES:

Figure 1: Grouping of teeth

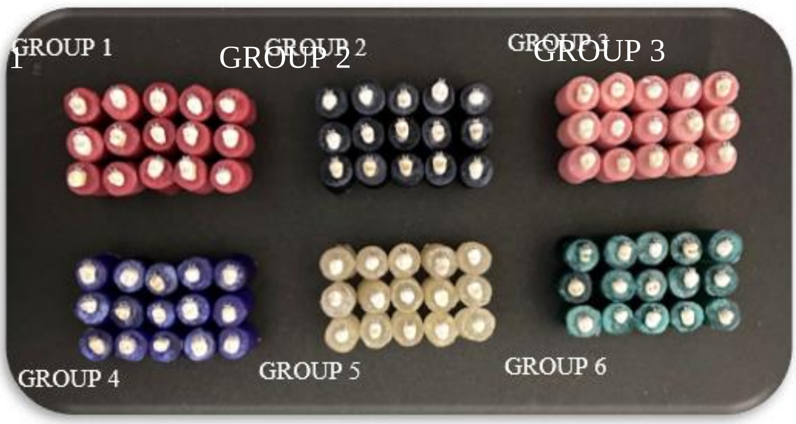

Figure 2: Rod transmitting Shear force

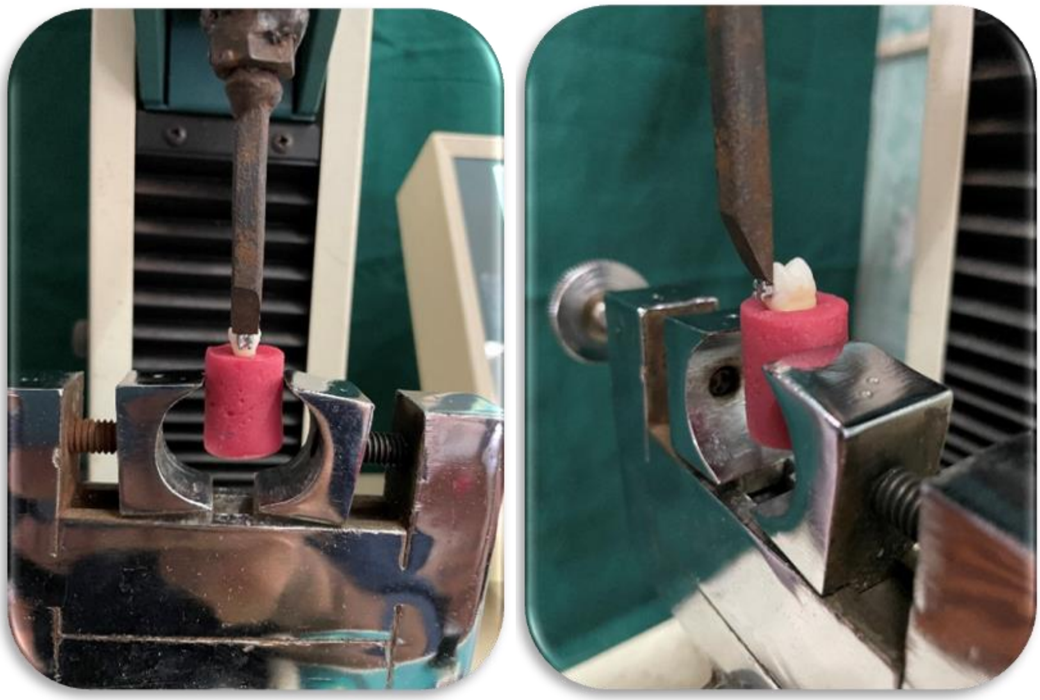

Figure 3: Descriptive data for shear bond strength

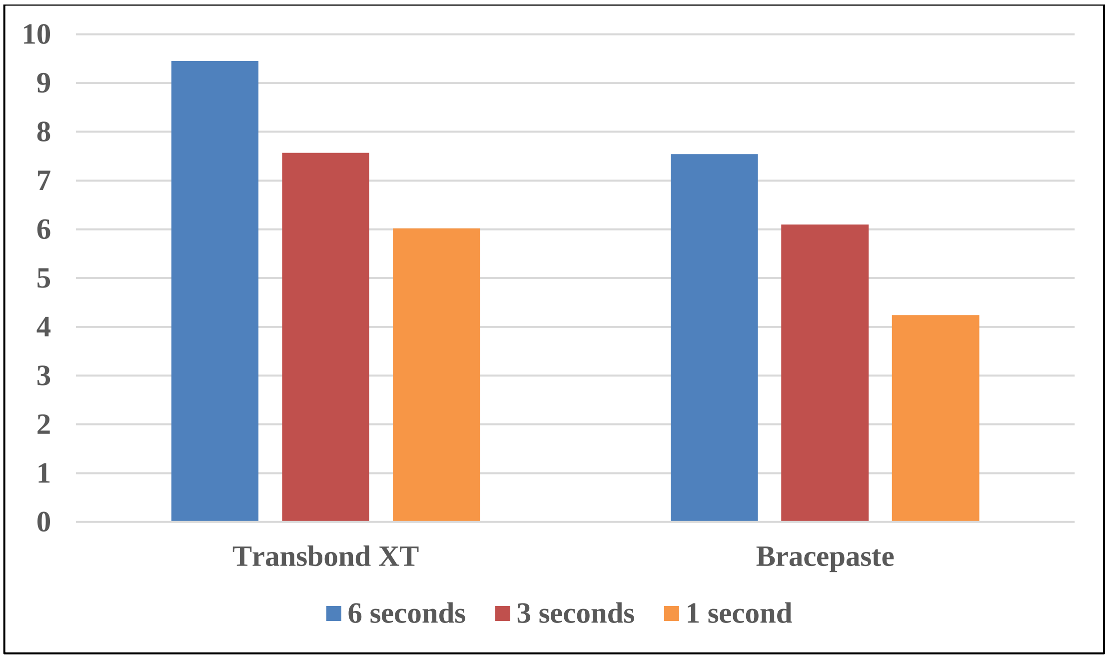

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Figure 4: Box plot for Mean Shear bond strength

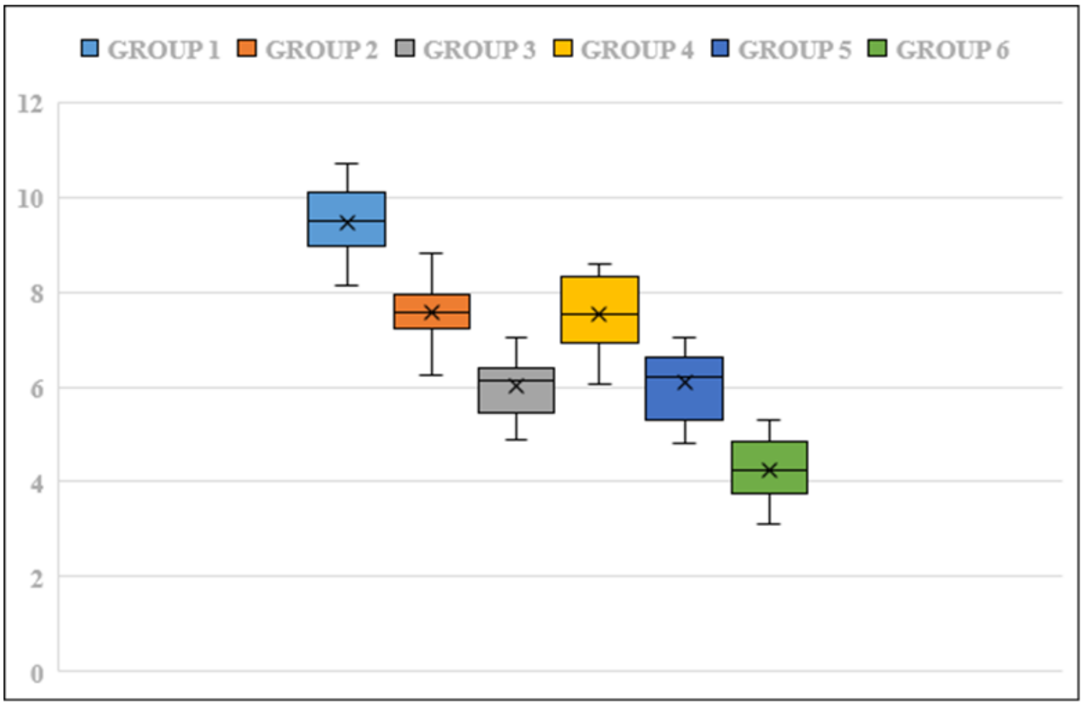

Figure 5: Box plot for Adhesive remnant index