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Comparison of Shear Bond Strength of Aligner Attachments using various Types of Composites

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ABSTRACT
BACKGROUND: The field of orthodontics has witnessed major advancements with the introduction of clear aligner therapy as an alternative to traditional fixed appliances. Initially, conventional braces—comprising metal brackets and wires—were the primary method for correcting malocclusions. These systems, though effective, often caused aesthetic concerns and oral discomfort. The evolution of digital technology and 3D imaging in the late 1990s led to the creation of clear aligners, which offered a more aesthetic, removable, and comfortable option for patients. Composite dislodgement in aligner therapy refers to the accidental detachment of composite attachments bonded to teeth, which aid in achieving precise tooth movements. These attachments enhance the grip and control of aligners, allowing effective force application. **AIM:** This study aims to analyse the shear bond strength of various types of composites for the long term performance of the composite attachments. **MATERIALS AND METHODS:** The study was conducted in Saveetha Dental College and Hospitals, Chennai, India. 15 extracted teeth were considered as samples for the study and were divided into 5 groups containing 3 teeth each. 5 variants of composite resins were selected of the same brand and assigned to each of the groups. Aligner attachments of size 3mm x 3mm were bonded in each h teeth on the buccal surface. Shear bond strength was calculated using a 1mm knife. Results were evaluated. **RESULTS AND DISCUSSION:** Group 1 composites (Bulk fill injectible) showed the highest compressive stress compared to others and a huge variation was seen in Bulk filled orthodontic composite. Maximum shear bond strength was also seen in group 1, with force bearing of 215.49N. Studies indicate that bracket debonding rates vary widely, ranging from 3% to 34% depending on factors such as adhesive type, bracket design, patient compliance, and treatment protocols. **CONCLUSION:** Among the materials tested, the Shofu Beautifil Injectable Bulk Fill Fluoride-Releasing Composite (Group 1) demonstrated the highest mean shear bond strength, indicating superior adhesion to enamel surfaces. This suggests that its combination of bulk-fill formulation, fluoride release, and balanced filler loading provides improved mechanical stability and bond integrity. The Beautifil Flow 03 (intermediate viscosity) also exhibited favorable bond strength, highlighting that medium-viscosity flowable composites can offer a good compromise between adaptability and resistance to dislodgement. In contrast, low-viscosity composites (Beautifil Flow 02) recorded the lowest bond strength values, suggesting limited suitability for situations demanding higher mechanical retention.
KEYWORDS: Aligners, Composite attachments, Displacement, Shear bond strength (SBS), Stress.

INTRODUCTION

The field of orthodontics has undergone remarkable advancements over the past few decades, particularly with the emergence of clear aligner therapy as a modern alternative to conventional fixed appliances. Traditional orthodontic systems, consisting of metal brackets and wires, have long been recognized for their effectiveness in correcting malocclusions. However, they often present aesthetic concerns, soft tissue irritation, and challenges in maintaining oral hygiene. The integration of digital technology and three-dimensional (3D) imaging in the late 1990s revolutionized orthodontic treatment and led to the development of clear aligners—transparent, removable thermoplastic trays designed to reposition teeth gradually and precisely [1].

Each aligner is fabricated through computer-aided design and applies controlled, incremental forces to specific teeth, allowing predictable and efficient tooth movement. Unlike fixed braces, aligners are virtually invisible and can be removed during eating and oral hygiene procedures, thereby enhancing aesthetics, comfort, and convenience [2]. They also minimize chairside time and clinical visits. Despite these advantages, the success of aligner therapy is highly dependent on patient compliance, as aligners must be worn for approximately 20–22 hours per day to achieve optimal results. Although clear aligners are effective in managing mild to moderate malocclusions, complex cases involving significant rotations or vertical discrepancies often still require fixed appliances for better biomechanical control [3].With continuous innovations such as improved thermoplastic materials, artificial intelligence–assisted treatment planning, and computer-aided modeling, aligner systems have become more precise, efficient, and widely accepted. Consequently, they have transformed patient expectations and clinical approaches in modern orthodontics[4].A critical factor influencing the effectiveness of clear aligner therapy is the performance and stability of composite attachments. These small resin projections bonded to tooth surfaces enable aligners to exert targeted forces necessary for complex tooth movements, such as extrusion, rotation, and torque control [4,5]. However, attachment dislodgement—the unintended detachment of these composites—remains a common clinical problem. It can occur due to improper bonding techniques, inadequate enamel preparation, insufficient curing, or mechanical stresses during aligner insertion and removal. Additionally, habits such as chewing hard or sticky foods and frequent manipulation of aligners can weaken the bond. Attachment loss can compromise aligner fit, disrupt planned tooth movement, and prolong treatment duration [6].

The shear bond strength (SBS) of the bonding material plays a crucial role in the longevity and success of aligner attachments. SBS measures the force required to detach a bonded composite from the enamel surface when subjected to a shearing load [7]. High SBS values indicate strong adhesion, reducing the likelihood of attachment failure during treatment. Conversely, low SBS may result in repeated debonding, affecting treatment accuracy and efficiency. Factors that influence SBS include the type of composite resin, bonding agent, enamel conditioning technique, light-curing protocol, and direction of applied force.

Achieving an optimal balance between adequate bond strength and enamel safety is essential for clinical success. Proper bonding protocols and the selection of suitable composite materials enhance attachment durability and minimize failure rates [8]. Understanding these factors is therefore fundamental to improving the predictability, efficiency, and overall success of clear aligner therapy in contemporary orthodontic practice.

MATERIALS AND METHODS

This in vitro study was conducted in the Department of Orthodontics, Saveetha Dental College and Hospitals, Chennai, India. A total of 15 extracted human teeth free from caries, cracks, or restorations were selected and stored in distilled water until use to prevent dehydration. The teeth were randomly divided into five groups, with three teeth in each group, based on the type of composite resin material used for bonding the aligner attachments.

Group distribution:

- Group 1: Shofu Beautifil Injectable Bulk Fill Fluoride-Releasing Composite
- Group 2: Shofu Beautifil Flow 02 (Low-viscosity flowable composite)
- Group 3: Shofu Beautifil Flow 03 (Intermediate-viscosity flowable composite)
- Group 4: Shofu Beautifil Bulk Orthodontic Composite
- Group 5: Shofu Beautifil Flow 10 (High-viscosity flowable composite)

Each tooth was cleaned and polished with non-fluoridated pumice and water using a rubber cup, then rinsed and dried thoroughly. The buccal surfaces were etched with 37% phosphoric acid for 30 seconds, rinsed with water, and air-dried. A thin layer of bonding agent was applied and light-cured according to the manufacturer's instructions.

Aligner attachments measuring 3 mm × 3 mm were fabricated using a standardized silicone mold to ensure uniform dimensions. The respective composite material was placed into the mold and light-cured for 20 seconds with an LED curing unit at an intensity of 1200 mW/cm².

After bonding, the samples were mounted in acrylic resin blocks, ensuring the buccal surface was parallel to the direction of applied force. The shear bond strength (SBS) of each attachment was tested using a universal testing machine. A 1 mm chisel-shaped knife edge was applied at the composite–enamel interface at a crosshead speed of 1 mm/min until bond failure occurred.

The SBS values (in MPa) were recorded and statistically analyzed to compare the performance of the different composite materials.

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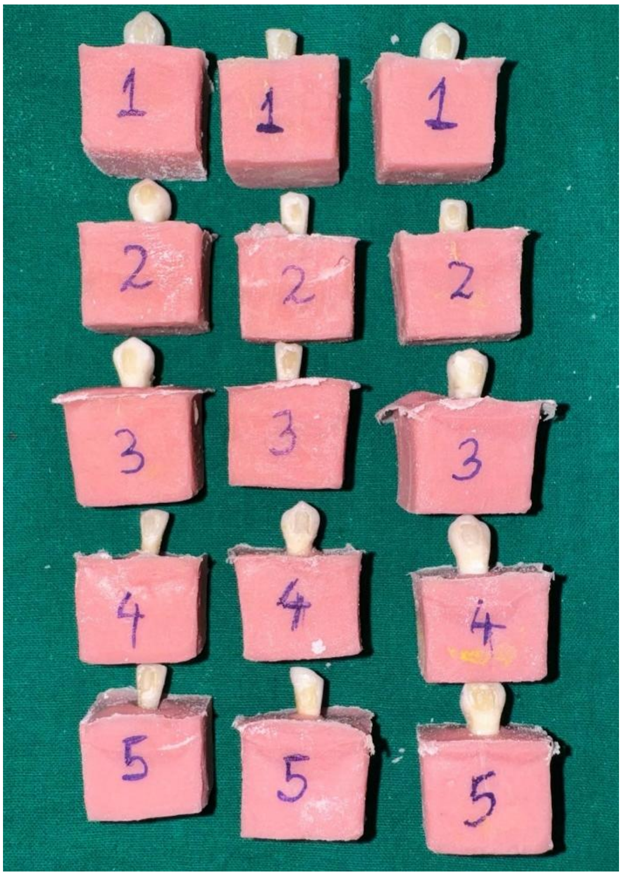

Image 1: Samples divided into 5 different groups.

Image 2: Testing the shear bond strength of the sample.

RESULTS

Among the tested materials, Group 1 exhibited the highest mean SBS (16.78 MPa), indicating superior bonding performance. This can be attributed to its bulk-fill property, fluoride release, and balanced filler content, which together enhance both mechanical retention and chemical adhesion to enamel. Group 3 also demonstrated high SBS (15.51 MPa), likely due to its intermediate viscosity that offers an optimal balance between flowability and filler concentration, ensuring effective penetration and bond uniformity.

In contrast, Group 2 recorded the lowest SBS (10.18 MPa), suggesting that low-viscosity composites may be prone to weaker mechanical bonding due to reduced filler content and higher polymerization shrinkage. Groups 4 and 5 showed moderate SBS values (14.12 MPa and 14.20 MPa, respectively), which may provide clinically acceptable performance but with some variability depending on handling and curing conditions.

The standard deviation analysis further revealed that Group 4 exhibited the greatest variability (±10.79 MPa), implying inconsistent bonding strength, possibly influenced by differences in curing depth or surface adaptation. On the other hand, Group 5 showed minimal variation (±1.85 MPa), indicating more predictable and stable bonding characteristics.

Based on the mean values, it is likely that Group 1 significantly outperforms Group 2 and potentially others in bond strength.

Clinically, an SBS value between 10–20 MPa is generally considered adequate for orthodontic bonding. All materials tested in this study fall within or above this range, confirming their suitability for aligner attachment bonding. However, the material with higher bond strength, such as the Beautifil Injectable Bulk Fill composite, ensures better longevity of attachments, minimizing the risk of dislodgement during aligner wear.

This finding is significant because attachment dislodgement disrupts tooth movement, compromises aligner fit, and prolongs treatment duration. Therefore, selecting a composite with optimal SBS is crucial to maintaining treatment efficiency and reducing chairside time for re-bonding procedures. Additionally, the fluoride-releasing property of Beautifil Injectable Bulk Fill may offer added advantages by enhancing enamel resistance to demineralization during long-term aligner therapy. The results of this study demonstrate that composite viscosity, filler content, and curing depth are key determinants of shear bond strength and, consequently, the durability of aligner attachments. The Beautifil Injectable Bulk Fill fluoride-releasing composite emerged as the most effective material, offering both high bond strength and potential preventive benefits. Intermediate-viscosity composites (Flow 03) also performed favorably, suggesting they may serve as a reliable alternative where flexibility and adaptability are required.

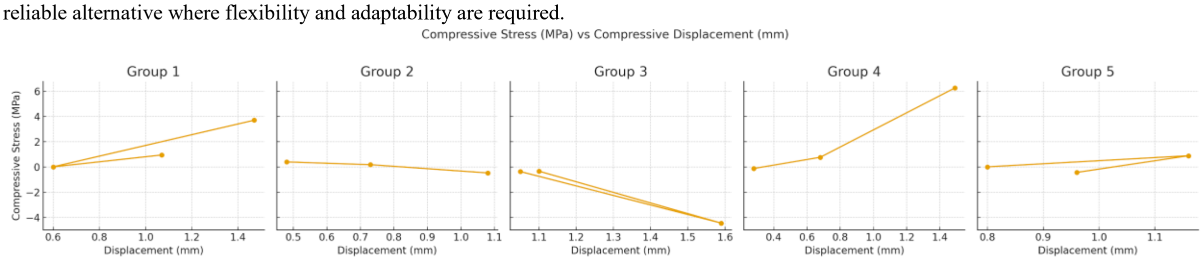

Image 3: Graph showing Compressive Stress (MPa) vs. Compressive Displacement (mm) for all five groups.

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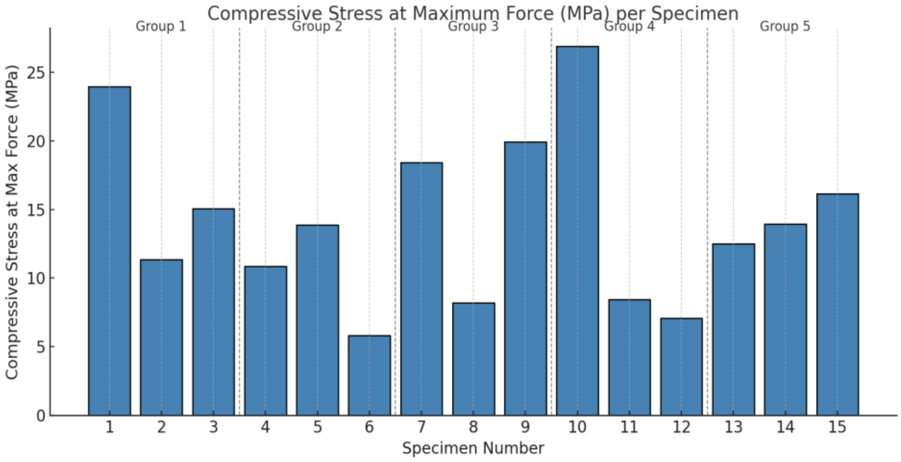

Image 4: Graph showing Compressive Stress at Maximum Force (MPa) for each specimen.

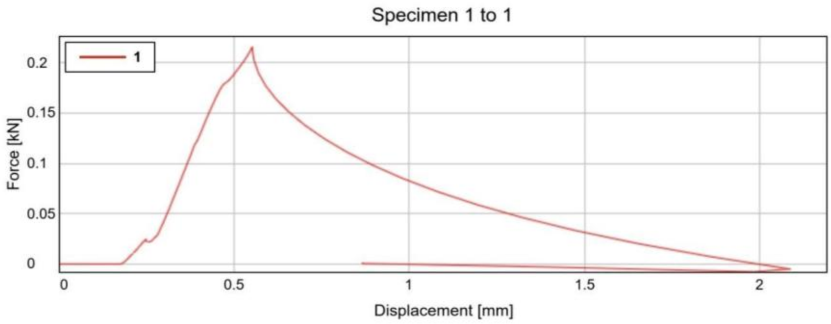

Image 5: Graph representing Force and displacement for a specimen of Group 1.

Specimen	Compressive Displacement (mm)	Compressive Stress (MPa)
1	1.47	3.70
2	0.60	0.01
3	1.07	0.95

Table 1: Compressive displacement and stress for Group 1 – Shofu Beautifil Injectable Bulk Fill Fluoride-Releasing Composite.

Specimen	Compressive Displacement (mm)	Compressive Stress (MPa)
4	1.08	-0.47
5	0.73	0.18
6	0.48	0.40

Table 2: Compressive displacement and stress for Group 2- Shofu Beautifil Flow 02 (Low Viscosity Flowable Composite).

Specimen	Compressive Displacement (mm)	Compressive Stress (MPa)
7	1.05	-0.36
8	1.59	-4.44
9	1.10	-0.33

Table 3: Compressive displacement and stress for Group 3 – Shofu Beautifil Flow 03 (Intermediate Viscosity Flowable Composite).

Specimen	Compressive Displacement (mm)	Compressive Stress (MPa)
10	1.49	6.25
11	0.68	0.77
12	0.28	-0.12

Table 4: Compressive displacement and stress for Group 4 – Shofu Beautifil Bulk Orthodontic Composite.

Specimen	Compressive Displacement (mm)	Compressive Stress (MPa)
13	0.80	0.01
14	1.16	0.89
15	0.96	-0.43

Table 5: Compressive displacement and stress for Group 5 – Shofu Beautifil Flow 10 (High Viscosity Flowable Composite).

Specimen	Maximum Force (N)	Compressive Stress at Maximum Force (MPa)	Specimen Label / Group
1	215.49	23.94	1
2	102.19	11.35	1
3	135.38	15.04	1
4	97.83	10.87	2
5	124.64	13.85	2
6	52.29	5.81	2
7	165.84	18.43	3
8	73.62	8.18	3
9	179.16	19.91	3
10	241.94	26.88	4
11	75.83	8.43	4
12	63.52	7.06	4
13	112.47	12.50	5
14	125.58	13.95	5
15	145.25	16.14	5

Table 6: This table represents the mechanical performance data obtained during shear bond strength testing of composite materials used for aligner attachments.

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DISCUSSION

This study provides valuable insight into the role of composite material properties in determining the success of aligner attachment bonding. The findings highlight that shear bond strength (SBS) is significantly influenced by factors such as composite viscosity, filler content, and formulation. Among the tested groups, the bulk-fill injectable composite demonstrated the highest SBS, indicating superior adhesion and mechanical stability. This can be attributed to its optimized filler distribution and fluoride-releasing capability, which may also contribute to enamel protection during treatment.

The comparatively lower bond strength observed in low-viscosity composites suggests that reduced filler content and higher polymerization shrinkage may compromise attachment retention. Interestingly, intermediate-viscosity composites showed favorable performance, indicating a balance between flowability and strength, making them clinically reliable alternatives.

Clinically, all tested materials fell within the acceptable SBS range (10–20 MPa), suggesting their general suitability for orthodontic use. However, higher bond strength materials are advantageous in minimizing attachment failure, reducing chairside time, and improving treatment efficiency. Despite its limitations, including small sample size and in vitro design, this study emphasizes the importance of appropriate material selection to enhance the predictability and longevity of clear aligner therapy.

CONCLUSION

Within the limitations of this in vitro study, it can be concluded that the type and viscosity of composite resin significantly influence the shear bond strength and thereby the longevity of aligner attachments. Among the materials tested, the Shofu Beautifil Injectable Bulk Fill Fluoride-Releasing Composite (Group 1) demonstrated the highest mean shear bond strength, indicating superior adhesion to enamel surfaces. This suggests that its combination of bulk-fill formulation, fluoride release, and balanced filler loading provides improved mechanical stability and bond integrity.

The Beautifil Flow 03 (intermediate viscosity) also exhibited favorable bond strength, highlighting that medium-viscosity flowable composites can offer a good compromise between adaptability and resistance to dislodgement. In contrast, low-viscosity composites (Beautifil Flow 02) recorded the lowest bond strength values, suggesting limited suitability for situations demanding higher mechanical retention.

All the materials tested, however, achieved shear bond strength values within the clinically acceptable range for orthodontic bonding (10–20 MPa), implying that each can be used effectively under appropriate clinical conditions.

Overall, the findings emphasize the importance of selecting a composite with optimal bond strength to minimize attachment dislodgement, ensure consistent tooth movement, and enhance the predictability and efficiency of clear aligner therapy. Future clinical studies involving dynamic oral conditions are recommended to validate these results and support evidence-based material selection for aligner attachment bonding.

SCOPE FOR FUTURE RESEARCH

Future research should include larger sample sizes and in vivo clinical trials to validate the laboratory findings under real oral conditions. Studies comparing different brands and formulations of composites, bonding systems, and curing protocols would help identify optimal material combinations for aligner attachments. Evaluating the effects of thermocycling, masticatory load, and moisture contamination on shear bond strength can further simulate intraoral conditions. Additionally, finite element analysis (FEA) and microscopic evaluation could provide deeper insights into the failure modes and stress distribution at the composite–enamel interface. Long-term studies assessing attachment retention rates, patient compliance, and treatment efficiency across different materials will contribute to evidence-based recommendations for clinical orthodontic practice. Incorporating advancements in nanocomposites and adhesive technology may also enhance future developments in aligner attachment bonding systems.

LIMITATIONS

This study was conducted in vitro using extracted human teeth, which may not accurately replicate the complex oral environment present in vivo. Factors such as salivary flow, masticatory forces, pH variations, and thermal cycling could influence the actual bond strength of composite attachments in clinical situations. The sample size (n=15) was relatively small, which may limit the statistical power and generalizability of the results. Additionally, only one brand of composite resin system (Shofu Beautifil) was tested, and variations in bonding agents, curing lights, or surface treatments were not explored. The absence of long-term cyclic fatigue or thermomechanical aging simulation also restricts the ability to predict long-term clinical performance and attachment durability.

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