Original Article

Shear Bond Strength of Self-Adhesive Versus Conventional Flowable Composites: An *In Vitro* Study

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ABSTRACT

Aim: As an emerging yet underexplored innovation in dentistry, self-adhesive flowable composites (SAFCs) represent a promising and enduring advancement in the dental material technology. Our study aims to evaluate the shear bond strength of two SAFCs and the bonding of conventional flowable composite (CFC) to permanent dentin. **Materials and Methods:** Thirty-six teeth were embedded in acrylic blocks, with the occlusal third removed to expose the underlying dentin. A cylindrical mold was positioned on the treated dentin surface and filled with the composite resin material to be evaluated. The prepared permanent dentin surfaces were randomly assigned to three groups based on the following application protocols: Group 1: Axo Uni Flow (AXIMACK, India); Group 2: Constic (DMG, Germany); and Group 3: 37% phosphoric acid etchant + Single Bond Universal + Filtek Z350 XT (3M ESPE, USA). The shear bond strength of the prepared specimens was measured by using a universal testing machine. The data were analyzed with Kruskal–Wallis one-way analysis of variance, followed by Dwass–Steel–Critchlow–Fligner pairwise comparisons. **Results:** Filtek Z350 XT (3M ESPE, USA) demonstrated higher shear bond strength values when compared to Constic (DMG, Germany) and Axo Uni Flow (AXIMACK, India). A significant difference was found between these materials. However, the shear bond strength of the two SAFCs tested did not differ significantly. **Conclusion:** The investigation's findings suggest that the SAFCs exhibited inferior shear bond strength compared with CFCs when bonded with permanent dentin.

KEYWORDS: *Adhesives, composite resins, dental bonding, materials testing, shear strength*

INTRODUCTION

Composite resins can be used as restorative materials to fabricate minimally prepared tooth restorations that are both clinically effective and esthetically pleasing. Composite resins have significantly evolved over the years. This evolution, encompassing clinical techniques and formulations, led to the introduction of flowable composites in the mid-1990s.[1] Compared to conventional resin composites, flowable composites allowed for easier manipulation with more adaptation due to their low viscosities.[2] Flowable composites are versatile and have been suggested for various restorative situations. These applications encompass pit and fissure sealants, repairs for amalgam and composite

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restorations, crown margin repairs, and preventive resin restorations. Additionally, they are employed to restore Class III and Class V cavities, repair porcelain restorations, and prepare cavities using air abrasion and cavity lining. Furthermore, they are advantageous for repairing enamel defects and incisal edges in anterior regions.[3]

A major advancement in dentin adhesives was the creation of the one-step adhesive system, which included bonding, priming, and etching within one bottle. By simplifying the operative procedures, these systems are more effective at reducing technique sensitivity, ensuring simultaneous demineralization and resin infiltration, and minimizing postoperative pain associated with mild self-etching adhesives.[4]

To enable bonding to dental hard tissues, dental composites are generally subjected to an additional conditioning phase by use of an adhesive solution.[5] Due to the technique sensitivity of current adhesives, the expected advancement for clinicians is the integration of bonding and composite technologies into a self-adhering restorative material.[6] Recently introduced self-adhering flowable composites (SAFCs) offer simplified, time-efficient procedures and have the advantage of ease of handling. These materials have qualities comparable to those of self-etch bonding methods, making them ideal for minor restorations and lining applications.[7] One could consider SAFCs a "step-less" technology.[8] Compared to conventional bonding agents, these composites offer several procedural advantages, including ease of application, fewer procedural errors (such as over-wetting and over-drying), and shorter chair times.[9]

SAFCs offer a distinct advantage: they can be directly applied to the cavity, removing the necessity for a separate adhesive system. SAFCs can bond to the tooth tissues via two mechanisms. In the initial stage, the phosphate group of glycerol phosphate dimethacrylate, the acidic monomer in the SAFCs, forms a chemical bond with the calcium ions in the tooth, followed by the micromechanical attachment of the polymerized monomers of SAFCs to collagen fibrils found in the tooth tissues.[10] Beyond their ease of use, SAFCs are pivotal in the evolution of adhesive dentistry, aligning with minimally invasive principles. These materials blend adhesive qualities with the mechanical robustness of traditional composites, meeting the demand for multifunctional dental solutions. Despite these advancements, the comparative efficacy of SAFCs in bonding to permanent dentin, relative to conventional flowable composites (CFCs), remains underexplored.

Ideally, SAFCs should bond to enamel and dentin as effectively as conventional systems that utilize separate resin composites and bonding agents. Since their inception, few studies have explored the physical and mechanical properties of SAFCs compared to traditional restorative systems.[11] While SAFCs have been acknowledged due to their ease of use and potential in minimally invasive dentistry, this study seeks to fill the critical gap in the literature by providing a detailed comparative analysis of their shear bond strength to permanent dentin against that of CFCs, underlining the implications for clinical decision-making and advancing the understanding of their performance in real-world dental applications. We hypothesize that the SAFCs and CFCs will have equal shear bond strength values when bonded to permanent dentin. Hence, this study aimed to evaluate the shear bond strength of two SAFCs and a CFC on bonding to permanent dentin.

Materials and Methods

Sample size

The sample size was computed to test the equality of median shear bond strength (Mega Pascals [MPa]) of three groups at a 5% level of significance between the three groups with 80% power for an effect size of 0.6. The total sample size required to apply parametric one-way analysis of variance (ANOVA) was 30. Anticipating the non-normality of the shear bond strength, we increased the total sample size to 36 to apply Kruskal–Wallis one-way ANOVA (nonparametric test).

The Institutional Ethics Committee approved the *in vitro* study (YEC2/582), which was carried out in the Department of Conservative Dentistry and Endodontics. The study utilized three different flowable composite resins: Axo Uni Flow (AXIMACK, India), Constic (DMG, Germany), and Filtek Z350 XT (3M ESPE, USA). The compositions of these composite resins are detailed in Table 1.

The study consists of three groups (sample size $n = 12$ in each group)

(1) Axo Uni Flow (AXIMACK) group
(2) Constic (DMG) group
(3) 37% phosphoric acid etchant + Single Bond Universal + Filtek Z 350 XT(3M ESPE) group

Thirty-six anonymized stored extracted human permanent premolars, extracted as part of orthodontic management, were selected. The teeth were embedded in acrylic blocks, and the occlusal third was removed using a low-speed water-cooled diamond bur to expose the dentin tissue. A smear layer was created by applying 600-grit silicon

Table 1: Composition of materials used in the study

Material	Manufacturer	Composition
Axo Uni Flow	AXIMACK, India	Methacryloyloxydecyl dihydrogen phosphate (MDP), BISGMA, UDMA, TEGDMA, and HEMA
Constic	DMG, Germany	MDP, BISGMA, EBADMA, UDMA, HEMA, TEGDMA, and HDMA
Filtek Z350 XT	3M ESPE, USA	Silane-treated ceramic, BISGMA, UDMA, TEGDMA, PEGDMA, and Bis-EMA

BISGMA = bisphenol A glycidyl methacrylate, UDMA = urethane dimethacrylate, TEGDMA = triethylene glycol dimethacrylate, HEMA = 2-hydroxyethyl methacrylate, EBADMA = ethoxylated bisphenol A dimethacrylate, HDMA = 1,6-hexanediol dimethacrylate

carbide paper on the dentin surfaces under water for 30 s. On the prepared dentin surface, a cylindrical mold measuring 4 mm in height and 3 mm in internal diameter was placed and filled with the composite resin material for testing. In the first group, a thin layer of Axo Uni Flow (AXIMACK) measuring 0.5 mm was applied for 15–20 s at moderate pressure. Light curing was carried out for 20 s after removing any excess material. On the dentin surface, the composite was placed in two 2-mm increments and allowed to cure to form 4-mm composite cylinders.

In the second group, a 0.5 mm layer of Constic (DMG) was administered with a Luer Lok™ syringe (BD, Franklin Lakes, NJ, USA) and worked into the surface for 25 s by using the provided brush. After removing any extra material, the layer was given a 20-s light cure. Next, two 2 mm applications of the composite were made, and after curing, 4-mm composite cylinders were formed on the dentin surface.

In the third group, etching and bonding were performed before the Filtek Z350-XT flowable composite was applied, and 37% percent phosphoric acid (Scotchbond, 3M ESPE) was used for 15 s during etching, followed by a rinse and air-drying. A bonding agent (Single Bond Universal, 3M ESPE) was administered and massaged for 20 s. After lightly air-drying for 5 s, light curing was performed for 10 s. The Filtek Z350-XT flowable composite was then added to the cylindrical mold in two increments and cured. The mold was removed before conducting the shear bond strength test.

Before testing the specimens for shear bond strength, they were all kept in distilled water for 24 h. Specimens were then clamped in the holder of a universal testing machine. A knife-edge blade applied force at the dentin–composite interface at a 1.0 mm/min crosshead speed until fracture. The measurements were recorded in MPa. Figure 1 depicts the specimen's

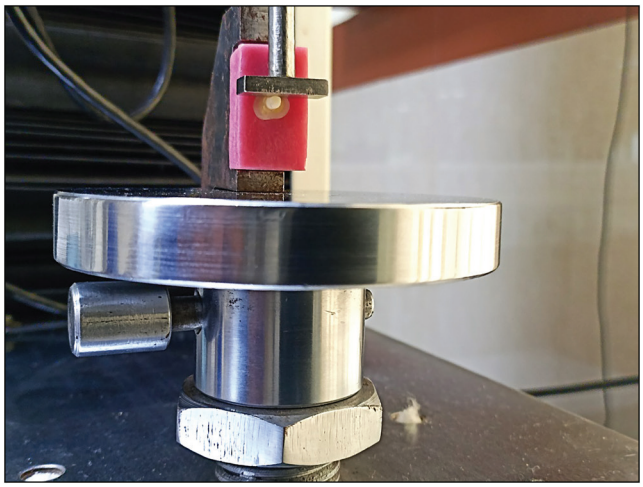

Figure 1: Shear bond strength testing

shear bond strength testing. Post-shear bond strength testing, a stereomicroscope was used to identify the fracture type—adhesive, cohesive, or mixed. This analysis provided additional insights into the bonding characteristics of each composite material.

Statistical analysis

All the collected data were analyzed using open statistical software Jamovi 2.3.24 (Sydney, Australia). Initially, data were summarized by computing mean (SD), and the normality of the data was tested by applying Shapiro–Wilks test. Considering the non-normality of shear bond strength (MPa) distribution within group 2, further data were summarized by computing the median and interquartile range. Kruskal–Wallis one-way ANOVA followed by Dwass–Steel–Critchlow–Fligner (DSCF) pairwise comparisons were used to compare the median shear bond strength of the three groups. P value < 0.05 was considered significant (the significance level was set at 5%).

Results

A description of the shear bond strength (MPa) is shown in Table 2. The Shapiro–Wilk test indicated the non-normality of shear bond strength in group 2 ($P = 0.003$). Kruskal–Wallis one-way ANOVA revealed a significant difference in the median of the three groups (Kruskal–Wallis test: $\chi^2(2df) = 14.7$, $P < 0.001$).

Median shear bond strength was significantly higher in the Filtek Z350 XT group compared to the Constic ($P = 0.008$) and Axo Uni Flow groups ($P = 0.003$) (DSCF pairwise comparison). However, there was no significant difference between the Axo Uni Flow and Constic groups [Table 3]. Figure 2 illustrates the distribution of shear bond strength (MPa) across the groups. Under stereomicroscopic examination, the conventional composite resin group predominantly

Table 2: Summary of shear bond strength in three groups

S no.	Group	Shear bond strength (MPa)						
		n	Mean (SD)	Shapiro–Wilk test *P* value	Median*	IQR**	Min.	Max.
1	Axo Uni Flow (AXIMACK, India)	12	3.54 (1.77)	0.749	3.35	1.48	0.860	7.20
2	Constic (DMG, Germany)	12	4.29 (1.64)	0.003	4.84	0.83	0.790	6.02
3	Filtek Z 350 XT (3M ESPE, USA)	12	14.60 (7.32)	0.170	14.84	11.23	2.650	23.17

*Significant difference in median observed. Kruskal–Wallis test: $\chi^2(2df) = 14.7$, $P < 0.001$.

**Inter-quartile range

Table 3: Pairwise comparisons—shear bond strength (MPa)

Group	Group	*P* value*
Axo Uni Flow (AXIMACK, India)	Constic (DMG)	0.264
Axo Uni Flow (AXIMACK, India)	Filtek Z 350 XT (3M ESPE, USA)	0.003
Constic (DMG, Germany)	Filtek Z 350 XT (3M ESPE)	0.008

*Dwass–Steel–Critchlow–Fligner pairwise comparisons

displayed mixed-mode fractures, indicating adhesive and cohesive failure mechanisms. In contrast, adhesive fractures were primarily observed in the SAFC groups at the resin–dentin interface, suggesting a weaker bond strength. The failure modes observed in the different groups are summarized in Table 4.

Discussion

Compared to CFCs, only a limited number of studies have described the mechanical and physical properties of SAFCs since their introduction. Other properties of these materials, such as microleakage, solubility, water sorption, and polishability, are predominant issues. Monitoring of bonding performance, as well as achievement of long-lasting restorations, are the major clinical concerns.[11] Goracci *et al.*[12] indicated that subsequent to thermocycling, the orthodontic brackets bonded using SAFCs demonstrated lower shear bond strength than that obtained with Transbond XT paste. Furthermore, vertise flow, an SAFC, has been the subject of *in vitro* research related to water sorption.[13] However, the bond strengths of SAFCs to permanent dentin remain largely unknown. This fact was the primarily responsible for choosing the two SAFCs in this study.

Tests of *in vitro* shear bond strength are essential for evaluating adhesive systems' efficacy and suitability in clinical settings.[14] Furthermore, despite the simplicity of shear bond strength testing, it has been proposed that this method might be more proficient in exploring the intricate interactions between composite materials and the substrate.[15] According to research by Bumrungruan and Sakoolnamarka, the microshear bond strength of SAFCs was less than that of flowable composites in a total-etch adhesive system but still comparable to that of flowable composites used with an all-in-one adhesive. The difference in bond strength across different adhesive techniques underscores the necessity of the present study to assess the shear bond strength of SAFCs compared to CFCs.[16]

In this study, the CFC group demonstrated higher shear bond strength compared to the SAFC groups. This enhanced bond strength is probably due to using phosphoric acid on dentin, which demineralizes the smear layer, exposing the collagen fibrils in the superficially demineralized dentin. This exposure likely boosts micromechanical interlocking between the adhesive and dentin.[17] Moreover, a single universal bond adhesive system containing 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) monomer significantly bolstered bond strength.[18] This occurs because the chemical interaction between hydroxyapatite and MDP forms a stable nanolayer, resulting in a more robust adhesive interface.[19] The formation of a stable "MDP-calcium" salt and nano-layering contributes to the high bond stability, as evidenced in both clinical and laboratory research works.[20] Additionally, including the ethanol solvent in the Single Universal Bond, which displaces moisture, enhances the penetration of the monomer into the exposed collagen network, thus forming a robust resin-demineralized dentin hybrid layer.[21] The CFC's bonding resin, composed of triethylene glycol dimethacrylate (TEGDMA), imparts additional mechanical strength, further explaining the observed higher bond strength values compared to SAFCs.[11]

The composition of Constic is diverse, including MDP monomer, bisphenol A glycidyl methacrylate, ethoxylated bisphenol A dimethacrylate, urethane dimethacrylate, 2-hydroxyethyl methacrylate (HEMA), TEGDMA, and 1,6-hexanediol dimethacrylate monomers. Notably, the MDP monomer in Constic forms stable 10-MDP calcium salts with hydroxyapatite, resulting in strong chemical bonding without causing significant decalcification.[22] The importance of MDP in the formulation is emphasized by its potential to create extended and more hydrophobic spacer chains than glycerol phosphate dimethacrylate.

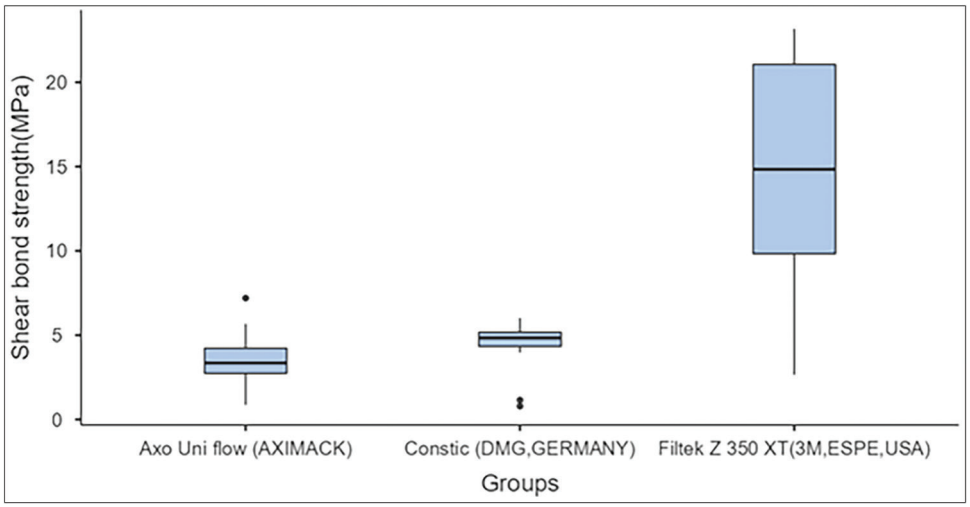

Figure 2: Box-plot showing distribution of shear bond strength (MPa)

Table 4: Types of bond failures observed in each group

Group	Adhesive failures	Cohesive failures	Mixed-mode failures
Axo Uni Flow	10	1	1
Constic	9	2	1
Filtek Z350 XT	2	4	6

In our research, SAFCs showed lower average shear bond strengths when applied without prior etching. This is consistent with the results of Vichi *et al.*[23] who found that the average shear bond strength of composites similar to dentin was under 4 MPa. This outcome is consistent with Juloski *et al.*'s[24] observation that brushing the SAFC as per the manufacturer's instructions does not significantly enhance its penetration into the dentin surface. Similarly, Poitevin *et al.*[25] observed reduced bond strengths for SAFC compared to self-etch systems on ground dentin. Hattar *et al.*[26] documented that the average shear bond strength of three self-adhering composites to dentin was below 6 MPa, attributing this to the superficial interaction with the tooth and inability to effectively dissolve the smear layer.

These results could also be associated with the inclusion of a bonding agent within the resin material, which may result in incomplete infiltration into demineralized dentin, degradation of exposed collagen, inadequate sealing of dentin tubules, and overall deterioration of the resin material.[27] This issue is further compounded by Tuloglu *et al.*'s[3] findings, which associate acidic functional monomers within the composite with lower bond strengths, leading to incomplete infiltration into the dentin. Bektas *et al.*[28] proposed that the diminished bond strengths may be due to the increased filler volume relative to the adhesive bonding agent. Fu *et al.*'s[29] observation of significantly lower bond strengths for these composites compared to one-step self-etch adhesives aligns with Miyazaki *et al.*'s[30] findings that increased filler loading increases the viscosity of the resin, thereby impeding dentin surface wetting. Despite containing HEMA that improves dentin wetting and enhances resin adhesion, the absence of solvents in SAFCs may limit their penetration into the dentin, impacting shear bond strength.[23,31]

The occurrence of mixed-mode fractures in the conventional composite group suggests robust interfacial bond strength, often leading to cohesive failures within the material, a characteristic of the effectiveness of total-etch adhesives.[32] In contrast, the primarily adhesive fractures observed in the SAFC group indicate their inherently weaker bond strength at the dentin interface, similar to self-etch adhesives.[33]

Our findings align with those reported in a systematic review of clinical studies, which demonstrated that while SAFCs offer ease of application and reduced chair time, their bond strength and long-term performance are generally inferior to those of conventional systems. This systematic review revealed that traditional composites exhibited better margin integrity and reduced margin color change at the 2-year mark when applied using the etch and rinse method. This underscores the importance of choosing the appropriate adhesive system based on the specific clinical scenario to ensure optimal restorative outcomes.[9]

In summary, while SAFCs are easier to use, they generally demonstrate lower bond strength compared to CFCs, a crucial factor for their clinical application in situations requiring robust bond strength.

The limitations of this study are primarily related to the limited range of materials tested. A broader selection of SAFCs might have provided a more nuanced understanding of their properties. Additionally, the variability in shear bond strength values can be credited to the heterogeneous nature of stress distribution at the interface, influenced by factors such as the bonding substrate, storage conditions, specimen preparation, and loading methods.[28] More *in vivo* research is essential to appropriately assess the clinical efficacy of these materials in light of these factors. Future research should also aim to validate our findings and explore a wider variety of SAFCs in laboratory and clinical settings.

Conclusion

SAFCs, noted for streamlining the restorative process by removing the need for adhesive application, show promise in dental applications. However, this study found that these composites exhibited decreased shear bond strength to permanent dentin when compared to CFCs. Additional clinical trials are required to validate these laboratory results and assess the efficacy of these materials in diverse therapeutic contexts.

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Conflicts of interest

There are no conflicts of interest.

Author contributions

AC: data collection, data interpretation, manuscript preparation, and critical revision. PMN: study conception and design. VFD: literature search, manuscript editing, and review. JK: literature search, manuscript editing, and review. AM: manuscript writing and review. LC: literature search, manuscript editing, and review. SSM: statistical analysis, interpretation of results, and contribution to manuscript writing. All authors approved the final version of the manuscript for publication.

Ethical policy and institutional review board statement

The institutional ethics committee of Yenepoya Dental College (Yenepoya Deemed to be University) approved this study (YEC2/582).

Patient declaration of consent

Not applicable.

Data availability statement

The data are available on request from the corresponding author.

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