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Quantitative evaluation of surface roughness and mass loss for different types of composite resins used for clear aligner attachments: an *in vitro* study

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Objectives: Due to a lack of thorough published research, orthodontists' clinical preferences influence the choice of composite resin for clear aligner attachments. According to a recent study on bonded attachments, all evaluated composite resins showed notable volumetric loss during brushing and heat cycling; however, brand-specific variations were observed. Nevertheless, mass loss and surface roughness are not directly represented by roughness and weight measurements. Therefore, the aim of this research was to compare the surface roughness and mass loss of six types of composite resins.

Materials and methods: Ninety rectangular composite resin attachments (2 × 4 × 1 mm) were fabricated using three flowable composite resins (Tetric PowerFlow, Filtek™ Supreme Flowable Restorative, and Clearfil Majesty Flow) and three restorative composite resins (Tetric PowerFill, Filtek™ Supreme XTE Universal, and Estelite Sigma Quick). Surface roughness and mass were recorded at baseline (T1) and after intervention (T2), which included thermocycling, simulated brushing, and abrasive testing. A 3D optical microscope profilometer and an analytical balance were used for measurement. Paired t-tests, one-way ANOVA, and Bonferroni *post hoc* tests were used for statistical analysis.

Results: Using paired *t*-tests, all tested composite resins showed a statistically significant increase in surface roughness and mass loss ($p < 0.05$), except for Tetric PowerFill, which showed no significant surface change ($p = 0.238$). This was reflected by a homogenous parallel line as an abrasive effect, without obvious irregularities. *Post hoc* comparisons of final roughness at T2 between groups revealed that Filtek™ Supreme XTE Universal exhibited the highest surface roughness and the greatest mass loss (2.4% of total weight).

Conclusion: Tetric PowerFill demonstrated superior resistance to surface wear and mass degradation, making it the most suitable material among those tested for long-term use as clear aligner attachments. In contrast, Filtek™ Supreme XTE Universal was the least resistant, indicating a higher need for clinical monitoring and potential replacement.

KEYWORDS

surface properties, profilometer, analytical balance, rectangular attachments, abrasive

1 Introduction

In 1999, clear aligner trays were introduced to the market as an invisible alternative to fixed orthodontic brackets. Significant progress has been made in the development of clear aligners, including the placement of composite to enhance the aligner's retention and ensure more precise and reliable tooth movements (Morton et al., 2017; Kircelli et al., 2023).

Clear aligners have undergone significant advancements across consecutive generations. The first generation relied merely on the aligner material to produce orthodontic movement, making it suitable only for minor orthodontic tooth movements (Hennessy and Al-Awadhi, 2016). The second generation introduced attachments and intermaxillary elastics to enhance its effects; however, only minimal improvement in tooth movement was observed (Kravitz et al., 2009). The third generation marked a shift toward automation, with manufacturer software incorporating features such as precision cuts, elastics, power ridges, and optimized attachments, allowing for further clinical modification (Hennessy and Al-Awadhi, 2016). Fourth-generation aligners introduced G4 attachments, improved designs for multi-plane movements, and enhanced extrusion and root control, particularly in open bite cases (Bichu et al., 2023; Hartshorne and Wertheimer, 2022). The fifth-generation aligners integrated SmartTrack™ material for improved force delivery and patient comfort, along with precision bite ramps and beveled attachments for deep bite correction (Tamburrino et al., 2020; Kravitz et al., 2009). Sixth-generation aligners featured SmartStage™ technology, enhancing vertical control and anchorage in extraction cases (Bichu et al., 2023). The seventh generation (Invisalign G7) focused on better root control and open bite correction in adolescents, while the eighth generation, released in 2020, improved posterior expansion and minimized crown tipping using advanced ClinCheck software and SmartForce™ technology (Bichu et al., 2023). Despite these advancements, camouflage therapy is frequently the only option available for addressing skeletal class II and class III malocclusions with clear aligners.

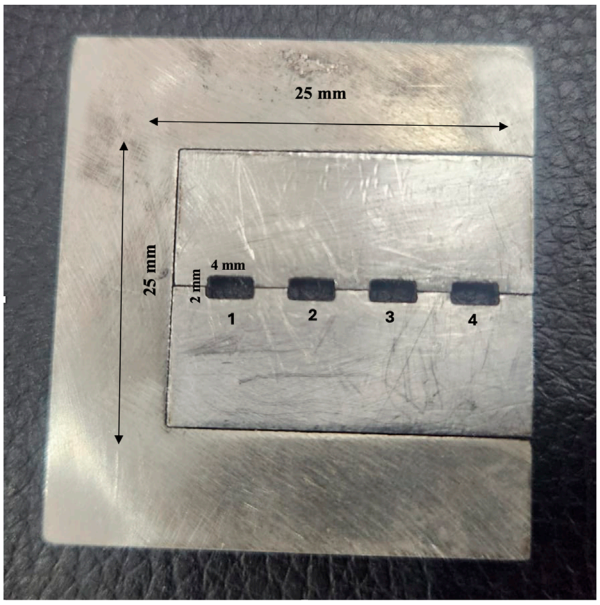

FIGURE 1
Customized split stainless-steel mold with dimensions of 25 mm × 25 mm × 1 mm having four slots (each slot with dimension of 4 mm × 2 mm × 1 mm) was used to form the composite resin attachment tested samples.

Worldwide, many restorative composite resin products have been introduced to the market by different companies, each with its own strength properties. For example, high or low viscosity can be controlled by increasing or decreasing the amount of diluent monomer, such as triethylene glycol dimethacrylate (TEGDMA) (Asmussen, 1975). In addition, the percentage of filler loading and size of filler particles vary between the restorative composite resins to fulfill specific indications of use (O'Brien, 2002; Lutz and Phillips, 1983). One of the most important factors to be evaluated when choosing the type of composite resin for clear aligner attachments is the surface wear of the composite resin. In 1972, researchers defined wear as a progressive loss of substance from the surface of a body as a result of mechanical action (Jones et al., 1972). In the oral cavity, it can be caused by mastication force, tooth brushing, and repeated insertion and removal of clear aligner trays (Lindquist and Emilson, 1990). It is crucial to evaluate the chosen composite resin, which will be used as the clear aligner attachment since this phenomenon influences orthodontic force delivery with time, especially in complex movements or long treatment cases (Weckmann et al., 2020).

Various resin-based composite attachments have been studied for their efficacy with clear aligners (Mantovani et al., 2019; D'Antò et al., 2019; Chen et al., 2021). The surface roughness of aligner attachments is consideration in clinical practice since it can significantly affect surface stress and structural integrity by changing the dynamics of the interaction between the aligner material and attachment (Suter et al., 2020). Erbas and Atik (2025) conducted a recent study in which they assessed the surface roughness and attachment accuracy of four composite resins under two different curing light intensities. While surface roughness results varied based on the type of composite and curing procedure, their findings showed that the 3M ESPE Filtek^{TM} Z350 XT Flowable Resin produced the maximum attachment accuracy. Despite these findings, there remains a scarcity of comprehensive research focusing on the surface roughness characteristics of composite resins specifically used for aligner attachments.

Due to a lack of thorough published research, orthodontists' clinical preferences influence the choice of composite resin for clear aligner attachments. The precise behavior of various attachment composite resins under aligner-simulated settings has not yet been thoroughly described despite these observations. According to a recent study on bonded attachments, all evaluated composite resins showed a notable volumetric loss during brushing and heat cycling; however, brand-specific variations were observed (Ocak et al., 2025). Nevertheless, mass loss and surface roughness are not directly represented by roughness and weight measurements. Therefore, the aim of this research was to compare the surface roughness and mass loss of six types of composite resins. Three of them were low-viscous flowable composite resins such as Tetric PowerFlow (Ivoclar Vivadent AG), Filtek™ Supreme Flowable Restorative (3M™ ESPE), and Clearfil Majesty Flow (Kuraray Medical, Tokyo, Japan). In addition, the other three were high-viscous restorative composite

TABLE 1 Tested composite resins[a].

Product	Manufacturer	Description	Composition	Filler size and load	Filler type	Significance
Tetric PowerFlow	Ivoclar Vivadent AG	Light-cure flowable composite	Bis-GMA, Bis-EMA, UDMA, and DCP	Nanohybrid 71%	Barium aluminum silicate glass, an iso-filler copolymer mix, and ytterbium fluoride	Short curing time = 3 s
Tetric PowerFill	Ivoclar Vivadent AG	Light-cure restorative material	Bis-GMA, Bis-EMA, UDMA, PBPA, DCP, and β-allyl sulfone	Nanohybrid 79%	Barium aluminum silicate glass, an iso-filler copolymer mix, ytterbium fluoride, and a spherical mixed oxide	Short curing time = 3 s
Filtek™ Supreme Flowable Restorative	3M™ ESPE	Light-cure flowable composite	Procrylat, Bis-GMA, and TEGDMA resins	Nano 65%	Non-agglomerated/non-aggregated surface modified 20 nm silica filler, a non-agglomerated/non-aggregated surface modified 75 nm silica filler, a surface modified aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4–11 nm zirconia particles), and ytterbium trifluoride filler with particle sizes ranging from 0.1 to 5.0 µm. The aggregate has an average cluster particle size of 0.6–10 µm.	0% bubble formation due to unique tip design
Filtek™ Supreme XTE Universal	3M™ ESPE	Light-cure restorative material	Bis-GMA (5–10 wt%), UDMA (5–10 wt%), TEGDMA (5–10 wt%), Bis-EMA6 (1%–10%), and polyethylene glycol dimethacrylate (PEGDMA) resins	Nano 78.5%	Non-agglomerated nano-silica of 20 nm filler size and agglomerated zirconia/silica nanocluster with the size of 5–20 nm	Exceptional handling properties
Clearfil Majesty Flow	Kuraray Medical	Light-cure flowable composite	(TEGDMA) Hydrophobic aromatic dimethacrylate dl-camphorquinone, accelerators, pigments, and others	Nano 81%	Silanated barium glass filler (average: 3 µm). Silanated colloidal silica (average: 20 nm)	Super esthetic due to highest filler content
Estelite Sigma Quick	Tokuyama Dental	Light-cure restorative material	Bis-GMA and TEGDMA	Supra-nano 82%	SiO_2, ZrO_2, and PFSC (200 nm)	Unique blending effect due to spherical shape particles

Bis-GMA, bisphenol A-diglycidyl dimethacrylate; Bis-EMA, ethoxylated bisphenol A dimethacrylate; UDMA, urethane dimethacrylate; DCP, tricyclodecane dimethanol dimethacrylate; PBPA, propoxylated bisphenol A dimethacrylate; DMA, dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; PEGDMA, polyethylene glycol dimethacrylate resins.
[a]All information is supported by each manufacturer's profile.

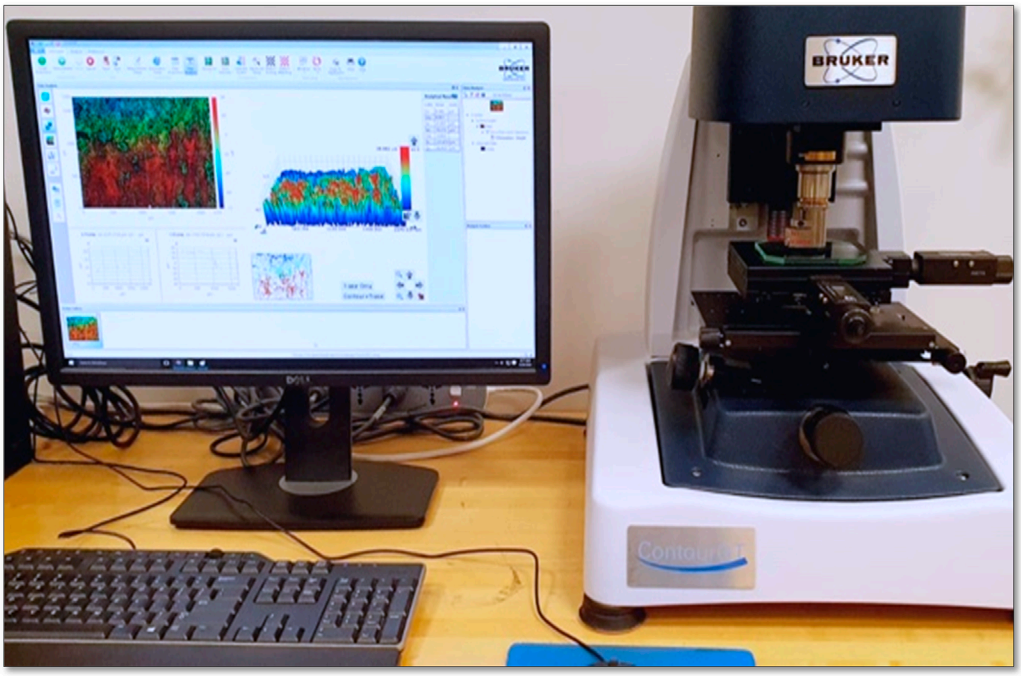

FIGURE 2
3D optical microscope profilometer (ContourGT Profiler, Bruker, United States) for composite resin surface roughness scanning at T1 and T2.

resins such as Tetric PowerFill (Ivoclar, Vivadent AG), Filtek™ Supreme XTE Universal (3M™ ESPE), and Estelite Sigma Quick (Tokuyama Dental, Japan).

2 Materials and methods

2.1 Ethical approval

The research project was registered with the CDRC of KSU # PR0146, and the study was conducted at the Physical Laboratory, King Saud University, Riyadh, Saudi Arabia.

2.2 Sample size calculation

The sample size was calculated using G*Power software set at 85% statistical power. The calculation revealed that a sample size of 12 attachments per group was required to detect statistically significant differences in surface roughness and mass loss at an alpha level of 0.05.

2.3 Sample preparation

A customized split stainless-steel mold with dimension of 25 mm × 25 mm × 1 mm was manufactured. It has four slots, and each slot with dimensions of 4 mm × 2 mm × 1 mm was used to form the composite resin attachments (Figure 1). The dimensions of the composite resin attachments were 2 mm in width, 4 mm in length, and 1 mm in thickness. All composites' resin attachments were made following the manufacturer's instructions for Tetric PowerFlow (Ivoclar Vivadent AG), Filtek™ Supreme Flowable Restorative (3M™ ESPE), Clearfil Majesty Flow (Kuraray Medical, Tokyo, Japan), Tetric PowerFill (Ivoclar, Vivadent AG), Filtek™ Supreme XTE Universal (3M™ ESPE), and Estelite Sigma Quick (Tokuyama Dental, Japan) (Table 1). Before curing, the attachments were covered with a polyester matrix strip (TDV Dental Ltda., Santa Catarina, Brazil) and were slightly pressed using a glass slide to form a smooth, compact surface. Finally, any excess was removed carefully, and then the samples were numbered with a permanent marker from 1 to 12.

2.4 Intervention

Each composite resin attachment's surface was scanned at T1 using a 3D optical microscope profilometer (ContourGT Profiler, Bruker, United States). Optical profilometer measurement is performed using a broadband light source that can detect surface irregularities (Sang et al., 2021). It provided a detailed 3D visualization, making it a highly effective and reliable tool for measuring surface roughness compared to other methods. An area of 2.279 × 1.709 mm^2 at the center of each sample was determined using the XY-linear translation stage (Marzhauser Wetzlar, Germany) (Figure 2). In addition, attachments were weighted using a digital analytical balance (Radwag Scale XA 60/220, Poland), with an accuracy of 0.00001 g, recorded as T1 (before intervention)

FIGURE 3
Digital analytical balance scale (Radwag Scale XA 60/220, Poland) for composite resin mass weight at T1 and T2.

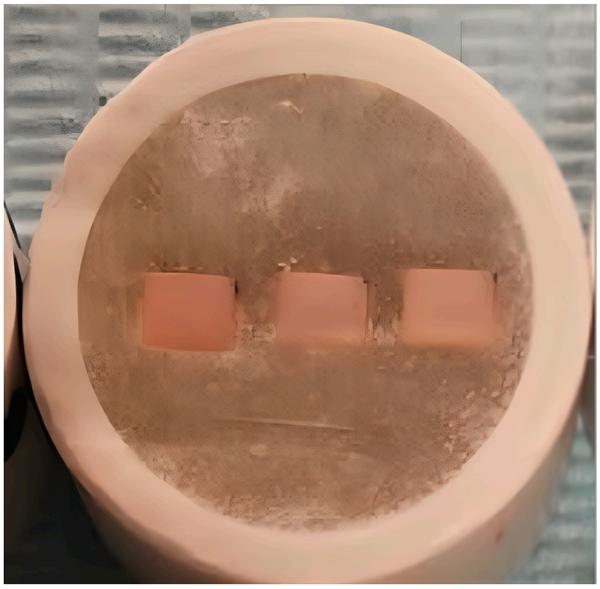

FIGURE 4
Composite resin rectangular attachments secured in a mold to be loaded in the tooth-brushing simulator machine ZM-3.8 (SD Mechatronik GMBH, Germany).

(Figure 3). To start the test, each group needed four molds, where each mold contained three rectangular attachments to be loaded to the tooth-brushing simulator machine ZM-3.8 (Figure 4).

First, the intervention started with the aging process, in which each sample underwent thermocycling aging following ISO/TS 11405:2015 guidelines, using SD Mechatronic TC 45 (Huber, Germany), in two distilled water baths for 30 s each. The first bath had a temperature of 5°C, and the second had a temperature of 55°C. A 10-s transfer time was considered for 10,000 cycles, equal to 1 year of aging (ISO/TS 11405:2015 Dentistry—Testing of adhesion to tooth structure). Second, the samples were placed in a tooth-brushing simulator following ISO TS No. 14569-2 guidelines using a tooth-brushing simulator machine ZM-3.8 (SD Mechatronik GmbH, Germany). A soft toothbrush (Colgate Twister toothbrush, Vietnam) and a mixture of water and toothpaste (Colgate Advanced Whitening toothpaste, United Kingdom) were used, and the machine was set to circular brushing movement for 24 h, equal to 1 year of wear (Figure 5) (Monteiro and Spohr, 2015). Next, the discs were cleaned for 10 min using distilled water in an ultrasonic bath (Driclave, Columbus Dental, United States) before the next step. Finally, abrasive wear was intentionally induced on the composite resin surface samples. Therefore, following the International Organization for Standardization (ISO) recommendation about the technical specification of two-body wear, the abrasive intervention by the tooth-brushing simulator was used (Ilie et al., 2017). It offers the advantages of simulating sliding movement without applying force and allows for computer-controlled movement. The antagonist brush that slides on the top of the composite resin sample surface was customized to be covered by 0.76-mm multilayered thermoplastic polyurethane–polyethylene terephthalate glycol–thermoplastic polyurethane (TPU–PETG–TPU) clear aligner material (Figure 6a). The machine was set on linear motion, was 12 mm in diameter, and had a speed of 30 mm/s. The movement was continued for 24 h and 68,500 cycles, equal to 1 year of use (Figure 6b). Mounted samples after the intervention process are shown in Figure 7.

2.5 Data collection

a. Surface roughness: T2 readings were collected using a 3D optical microscope profilometer (Contour GT Profiler, Bruker, United States), and the variable was expressed in µm as a roughness (Ra) value. This value represents the average value that expresses the mean distance between the peaks and valleys of the surface profile.
b. Mass loss: attachments were weighed again after intervention as T2 using a digital analytical balance (Radwag Scale XA 60/220, Poland). For each reading, an average of three readings was considered.

2.6 Statistical analysis

SPSS version 23 (SPSS Inc., IBM, Chicago, Illinois, United States) was used to gather and analyze the data using descriptive statistics such as mean and standard deviation. The normality of the data was evaluated using the Kolmogorov–Smirnov test, which showed normal data distribution. A paired t-test was used to compare the surface roughness and mass loss between pre- and post-intervention readings for each group. Subsequently, a one-way ANOVA test with a p-value of < 0.05 (which indicates significance) was used to verify the presence of differences in the variables between the six experimental

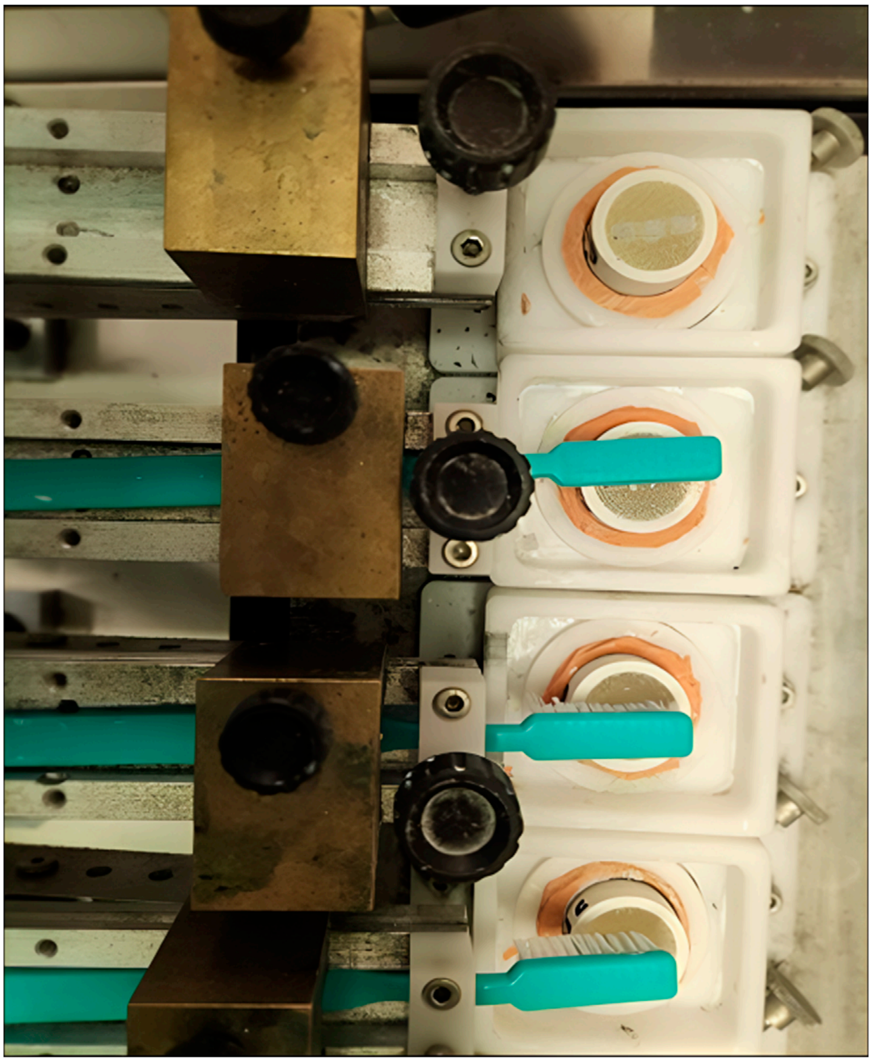

FIGURE 5
Second intervention: tooth brushing using a soft toothbrush (Colgate Twister toothbrush, Vietnam) and a mixture of water and toothpaste (Colgate Advanced Whitening toothpaste, United Kingdom) using tooth-brushing the simulator machine ZM-3.8 (SD Mechatronik GMBH, Germany) following ISO TS No. 14569-2 guidelines.

groups. To account for the increased risk of type I error due to multiple comparisons, the significance level was adjusted using the Bonferroni correction.

3 Results

3.1 Surface roughness

3D optical microscope profilometer data were analyzed using a paired *t*-test for surface roughness, which showed an overall increase in the materials' surface roughness from T1 (initial reading) to T2 (final reading) within each composite resin group (Table 2). A statistically significant change was detected in all groups of composite resins, except for the Tetric PowerFill group, which showed $p = 0.238$ and reflected a homogenous parallel line as an abrasive effect without obvious irregularities (Figure 8). On the other hand, a highly significant difference ($p < 0.01$) was observed in the Tetric PowerFlow composite resin group, which presented an irregular surface with varying elevations and depressions (Figure 9).

In addition, *post hoc* analysis was used to compare the final roughness (T2) between the tested composite resin material groups, and only Filtek™ Supreme XTE Universal composite resin exhibited statistically greater roughness than all other resin composites ($p < 0.05$) (Table 3). The profilometer images showed great variation within the samples, displaying a combination of smooth parts along with hills and valleys of varying heights and depths (Figure 10).

3.2 Mass loss

Paired *t*-tests for each experimental group showed a highly significant difference ($p < 0.01$) in mass loss after the intervention

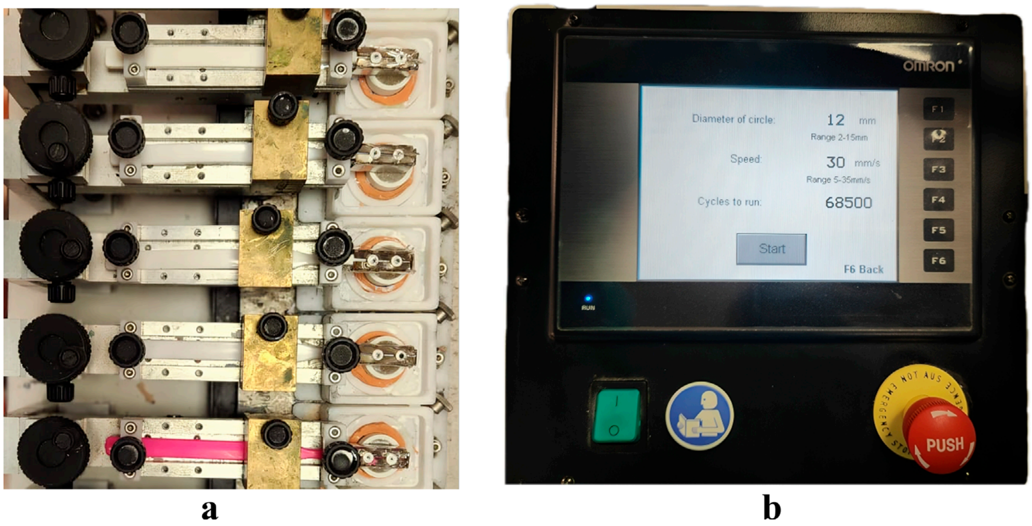

FIGURE 6
Last intervention: **(a)** surface abrasion formation by customized toothbrush loaded in tooth brushing simulator. **(b)** The machine was set on linear motion, with 12 mm diameter and a speed of 30 mm/s. The movement was continued for 24 h and 68,500 cycles.

in all composite resin groups. Filtek™ Supreme XTE Universal demonstrated the highest amount of mass loss, which accounted for 2.4% of the total weight. On the other hand, the minimum mass loss was found in Tetric PowerFill and Clearfil Majesty Flow, which was 1.19% of the total weight (Table 4).

4 Discussion

Dental composite resins are polymer-based materials composed of two main components, namely, organic elements (resin matrix, the coupling agent, and the initiator) and inorganic particles (Moszner and Salz, 2001). Organic resin matrix is usually based on methacrylate as 2,2-bis-[4-(2-hydroxy-3-methacryloyloxypropyl) phenyl] propane (bis-GMA), ethoxylated bis-GMA (EBPDMA), 1,6-bis-[2 methacryloyloxyethoxycarbonyl-amino]-2,4,4-trimethylhexane (UDMA), dodecanediol dimethacrylate (D3MA), or TEGDMA (Peutzfeldt, 1991). It plays a major role in keeping the material flowable at room temperature and then transforms it to a solid polymer upon curing (Wright, 2018). The second part is inorganic fillers such as glass, quartz, colloidal silica, or zirconia, which reinforce the material's strength, provide radiopacity, and enhance the handling properties. The filler size, shape, type, and loading percentage have an impact on the mechanical, optical, thermal, and polymerization shrinkage properties (Ferracane and Palin, 2012). One study found that it is difficult to describe the exact filler content differences between commercial materials (Randolph et al., 2016). In addition, it is challenging to accurately evaluate the effect of different resin compositions based on the filler size, type, or shape on specific physical or mechanical properties (García-Contreras et al., 2015).

In our research, we used six different types of composite resins, classified based on filler size and loading percentage, to evaluate their wear behavior through surface roughness measurements and mass loss. The experiment intervention started with an aging process involving thermocycling between low (5°) and high (55°) water bath temperatures simultaneously, which is equal to 1 year of aging. This aging process simulates the harsh intraoral environment, which can be as simple as oral enzymatic degradation and water sorption to as hard as mastication and parafunctional habits (Jaramillo-Cartagena et al., 2021; Nasoohi et al., 2017). Generally, thermocycling as an aging process causes coupling agents' hydrolysis that affects the mechanical properties of the material, such as increasing the surface roughness (Delaviz et al., 2014). In addition, composite resins are used as clear aligner attachments to deliver orthodontic forces and retain the aligners. These attachments undergo repeated friction during placing and removing of the aligners, which causes surface roughness with time. As a result, plaque retention, composite resin discoloration, and subsequent failure of the restoration will take place (Pietrokovski et al., 2022). Because of that, the surface quality of the composite resin is one of the most important factors to be evaluated for esthetic and mechanical success.

In this *in vitro* study, overall increased roughness was found in all composite resin groups compared before and after the intervention, except in the Tetric PowerFill group, where its surface was affected the least. The Tetric line was introduced to the market by the company Ivoclar (Vivadent, Liechtenstein) (ISO 4049:2019). Researchers found a unique network homogeneity by integrating an addition–fragmentation chain transfer (AFCT) reagent in the organic matrix to improve the physical properties of Tetric PowerFill composite resin by internal molecular reorganization during curing (Gorsche et al., 2014). In addition, among all six groups, Tetric

FIGURE 7
Example of composite resin rectangular attachments of the mounted sample post intervention.

PowerFill has the maximum percentage of nanohybrid filler particles (79%), like the conventional composite resin, which improves flexural strength, fracture toughness, and wear resistance, indicating superior mechanical stability (Turssi et al., 2005). Alsahafi et al. (2023) evaluated volumetric wear of different types of bulk-fill composite resins, where Tetric PowerFill was one of the groups, after simulating chewing force at a load of 5 kg. They found no statistically significant difference until 500,000 load cycles were reached, a threshold that was not attained in this study (Alsahafi et al., 2023). On the other hand, Filtek™ Supreme Flowable Restorative was proposed to score the worst, but its composition of spherical mixed oxide pearls improved its performance even with the least

TABLE 2 Means and standard deviation (SD) of initial (T1) and final (T2) roughness (μm) after thermocycling, simulated tooth brushing, and abrasive testing within each group.

Material	T1 (SD) (μm)	T2 (SD) (μm)	P
Tetric PowerFlow	8.772 (2.04)	9.974 (2.06)	<0.01**
Tetric PowerFill	9.497 (1.56)	9.510 (1.28)	0.238
Filtek™ Supreme XTE Universal	8.853 (1.08)	9.452 (1.4)	<0.05*
Filtek™ Supreme Flowable Restorative	9.397 (1.25)	9.452 (1.4)	<0.05*
Clearfil Majesty Flow	9.297 (1.83)	10.414 (1.96)	<0.05*
Estelite Sigma Quick	9.593 (1.4)	10.666 (2.12)	<0.05*

(T1), pre intervention, (T2), post intervention.*The mean difference is significant at the 0.05 level, **The mean difference is highly significant at the 0.01 level.

amount of filler loading (Lee et al., 2005). This conclusion is supported by Ipek and Bilge (2024), who compared the surface roughness of different flowable composite resins after immersion in liquids at different pH values. They found that composite resin with supra-nano spherical filler content recorded lower Ra values due to the homogeneity of their spherical structure (Ipek and Bilge, 2024). Moreover, among all the experimental groups, Filtek™ Supreme XTE Universal composite resin showed the highest surface roughness. This can be explained by the material composition of the filler, which is composed of nanocluster fillers (~78.5%) that offer excellent esthetics and polish retention but may be more prone to surface degradation under repetitive mechanical stress. They are a combination of non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4–11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4–11 nm zirconia particles) (by manufacturer). The nano-fillers are weakly bonded within the organic matrix and can be easily detached from the matrix when continuous abrasive force is applied, resulting in a rougher surface that appears under the microscope as different heights of hills and depths of pits (Costa et al., 2007). Moreover, the presence of the zirconia filler plays a role in increasing surface roughness due to its hardness. The abrasive force will tend to remove the organic matrix faster than the hard zirconia fillers, which causes the variation in depth and hills (Costa et al., 2007). In addition, as a result of continuous abrasive force simulating 1 year of placing and removing the clear aligner trays, some mass loss was expected. The statistical analysis showed a highly significant mass loss in all experimental groups. It was the maximum in the Filtek™ Supreme XTE Universal composite resin by 2.4% of the total weight. Such a finding was proven in a recent study when surface roughness was evaluated after using two different finishing and polishing systems on different types of composite resins (Vinagre et al., 2023).

The results of surface roughness testing research are impacted by many factors, such as the surface preparation, type of the counterpart's material, test machines, load applied, aging process, and the experimental materials. Different experimental conditions and counterparts were used, but none of them included clear

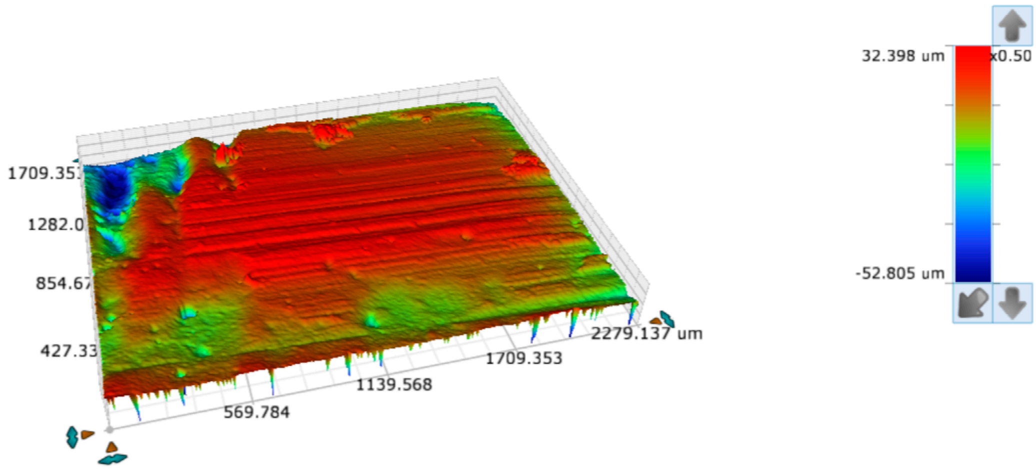

FIGURE 8
Tetric PowerFill composite resin 3D optical microscope picture of T2 surface roughness in μm as (Ra) value.

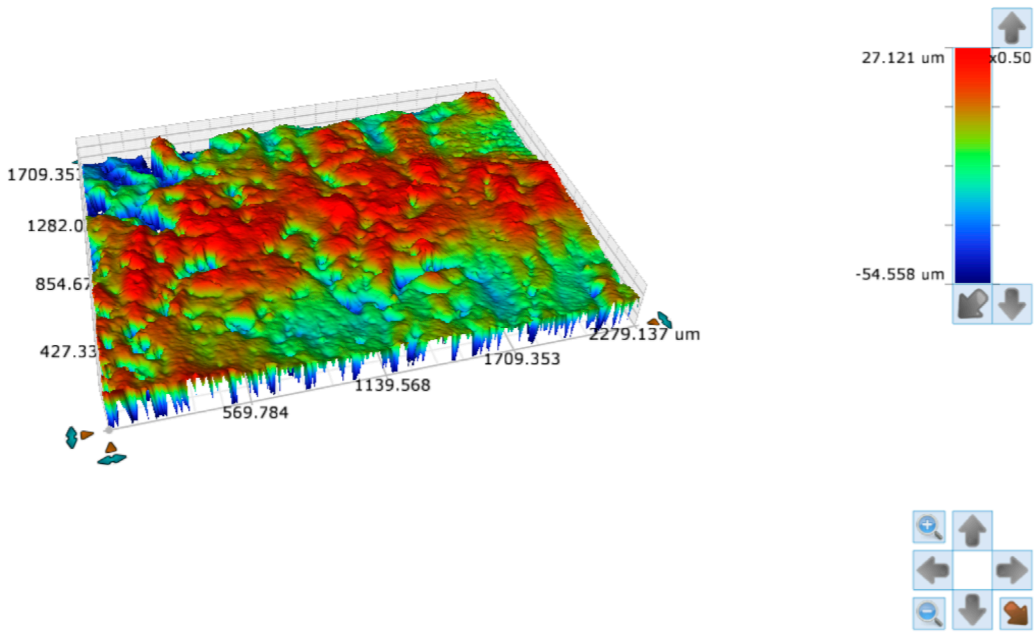

FIGURE 9
Tetric PowerFlow composite resin 3D optical microscope picture of T2 surface roughness in μm as (Ra) value.

aligner material as abrasive counterparts in a wet environment, which makes it difficult to compare the presented results with previous studies. Further clinical studies are recommended for long-term *in vivo* research to evaluate the performance and longevity of different composite resin attachment materials in actual oral environments.

5 Limitation and recommendation

This study has several limitations. The study was conducted under controlled laboratory conditions, which may not fully replicate the oral environment. Variables such as saliva, pH fluctuations, mastication forces, and temperature changes were

TABLE 3 *Post hoc* dependent variable; profilometer roughness (μm) between all type of composite resins.

Material	Tetric PowerFlow	Tetric PowerFill	Filtek™ Supreme XTE Universal	Filtek™ Supreme Flowable Restorative	Clearfil Majesty Flow	Estelite Sigma Quick
Tetric PowerFlow		0.476	2.95[a]	0.522	−0.44	−0.69
Tetric PowerFill	−0.476		2.48[a]	0.045	−0.916	−1.169
Filtek™ Supreme XTE Universal	−2.95[a]	−2.48[a]		−2.43[a]	−3.39[a]	−3.64[a]
Filtek™ Supreme Flowable Restorative	−0.522	−0.045	2.43[a]		−0.96	−1.21
Clearfil Majesty Flow	0.44	0.91	3.36[a]	0.962		−0.252
Estelite Sigma Quick	0.692	1.169	3.649[a]	1.214	1.214	

[a]The mean difference is significant at the 0.05 level.

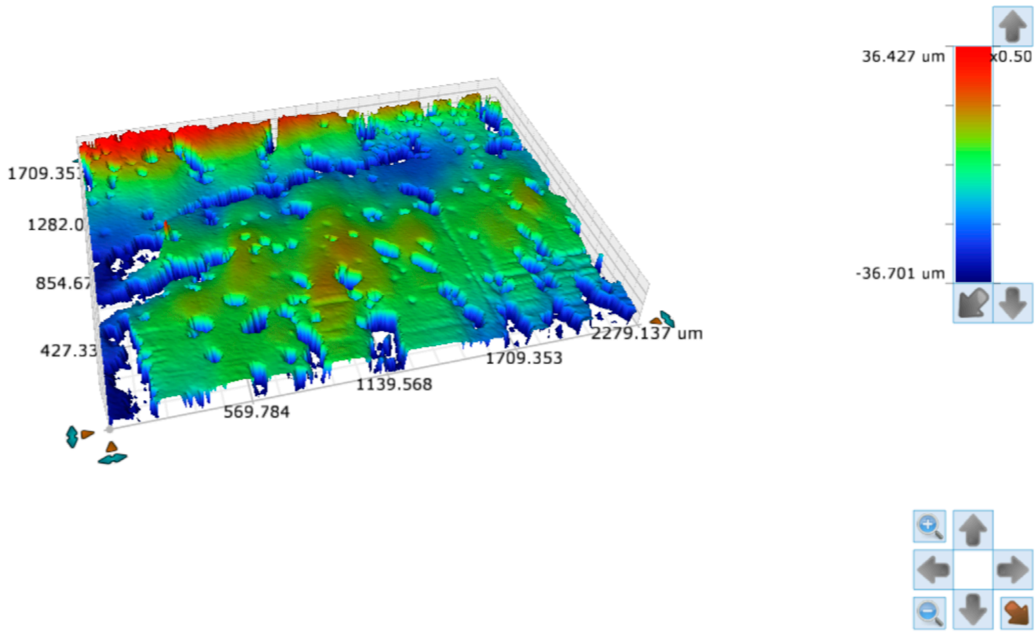

FIGURE 10
Filtek™ Supreme XTE Universal composite 3D optical microscope picture of T2 surface roughness in μm as (Ra) value.

not included, potentially affecting the generalizability of the results to clinical settings. For example, cyclic forces from aligner insertion/removal or chemical effects of saliva were not explicitly simulated. The sample size used for each composite resin material was relatively small, which may affect the statistical power and limit the detection of smaller but clinically relevant differences. The study measured surface roughness and mass loss over a short simulation period. Long-term wear and degradation patterns were not assessed, which are crucial for understanding clinical performance over the course of aligner therapy. Further research, including clinical trials, would be needed to confirm these trends *in vivo*.

6 Clinical implications

The results of this study underscore the importance of selecting composite resin materials for clear aligner attachments based not only on their esthetic and handling properties but also on their

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TABLE 4 Means in grams of initial (T1) and final (T2) difference of mass loss (*mg*) and percentage loss (%) after thermocycling, simulated tooth brushing, and abrasive testing within each group.

Material	T1 *mg*	T2 *mg*	T1-T3 *mg*	%	P
Tetric PowerFlow	51.2	50.4	0.85	1.66	<0.001*
Tetric PowerFill	58.5	57.8	0.70	1.19	<0.001*
Filtek™ Supreme XTE Universal	54.5	53.1	1.3	2.4	<0.001*
Filtek™ Supreme Flowable Restorative	43.4	42.6	0.76	1.75	<0.001*
Clearfil Majesty Flow	54.4	53.7	0.65	1.19	<0.001*
Estelite Sigma Quick	51.6	50.9	0.67	1.29	<0.001*

(T1), pre intervention, (T2), post intervention,*the mean difference is highly significant at the 0.01 level.

mechanical resilience. Given the frequent insertion and removal of aligners and their associated abrasive forces, materials with superior wear resistance are crucial for maintaining attachment integrity, force delivery accuracy, and long-term treatment efficacy. Tetric PowerFill, due to its minimal surface roughness change and lower mass loss, may offer improved clinical longevity and reduced need for replacement or repair during orthodontic treatment. In contrast, materials such as Filtek™ Supreme XTE Universal may require more frequent monitoring and maintenance due to their higher degradation under simulated intraoral conditions.

7 Conclusion

Within the limitations of this *in vitro* study, Tetric PowerFill demonstrated the highest resistance to surface degradation, with $p = 0.238$. Conversely, Filtek™ Supreme XTE Universal exhibited the greatest increase in surface roughness and the highest volumetric mass loss (2.4% of the total weight) following simulated intraoral aging, brushing, and abrasive conditions. Further clinical studies are recommended to validate these findings *in vivo*.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

RRA: Funding acquisition, Resources, Project administration, Formal analysis, Visualization, Validation, Writing – original draft, Data curation, Investigation, Conceptualization, Methodology, and Software. NA: Funding acquisition, Writing – review and editing. AA: Funding acquisition, Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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