Effect of Surface Treatments on Push-out Bond Strength of Calcium Silicate-based Cements to Fiber Posts

Amr Elnaghy (aelnaghy@mans.edu.eg)
Department of Endodontics, Faculty of Dentistry, Mansoura University, Mansoura, Egypt
Ayman Mandorah
Taif University
Ali Hassan
King Abdulaziz University
Alaa Elshazli
Mansoura University
Shaymaa Elsaka
Mansoura University

Research Article

Keywords: Biodentine, Fiber post, Push-out bond strength, Surface treatments, Titanium tetrafluoride

Posted Date: December 15th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-123467/v1

Version of Record: A version of this preprint was published on March 19th, 2021. See the published version at https://doi.org/10.1186/s12903-021-01518-y.

Abstract

Background: To evaluate the effect of surface treatments on the push-out bond strength of Biodentine (BD) and white mineral trioxide aggregate (WMTA) to fiber posts.

Methods: Two brands of fiber posts were used: Reblida post; RP and RelyX post; RX. Each type of post was divided into four groups and exposed to surface treatment as follows: Control (no treatment), sandblasting (SB), hydrofluoric acid (HF), and TiF_4 4 wt/v%. Push-out bond strength of BD and WMTA to glass fiber posts was assessed. Data were statistically analyzed.

Results: BD showed higher bond strength than WMTA ($P < 0.001$). The push-out bond strength for posts treated with TiF4 4 wt/v% showed greater bond strength than the other surface treatments ($P < 0.05$). The BD/RP-TiF_4 4 wt/v% showed the greater characteristic bond strength (σ_0) (15.93) compared with the other groups.

Conclusions: The BD/RP-TiF_4 4 wt/v% showed greater bond strength compared with the other groups. The TiF_4 4 wt/v% surface treatment enhanced the bond strength of BD and WMTA to glass fiber posts than the other treatments. Surface treatment of fiber post with TiF_4 4 wt/v% could be used to improve the bond strength with calcium silicate-based cements.

Background

Calcium silicate-based cements (CSCs) revealed favorable clinical outcomes with different clinical applications [1–3]. Biodentine (BD; Septodont, Saint Maur des Faussés, France) and white mineral trioxide aggregate (WMTA) are CSCs that were used for different applications in endodontic treatment including pulp capping, repair of root perforations, pulpotomies, apical barrier, regenerative endodontics, and obturation of the entire root canal space [4–9]. MTA CSCs materials have certain limitations, including long setting time, discoloration of teeth, and difficulty in handling lead to the development of different CSCs to overcome these disadvantages [10–12].

One of the applications of CSCs is the treatment of non-vital immature permanent teeth. This procedure is established by disinfection of root canal, placement of apical barrier together with root-filling materials [13]. The fracture resistance of simulated immature permanent teeth used BD with fiber post was compared with different canal filling materials [4]. It was suggested that BD combined with fiber post might reinforce the immature teeth with an apical BD plug [4]. Fiber posts improved the fracture resistance of the tooth because their flexural modulus mimic to that of dentin [4, 7, 14–17]. This biomimetic characteristic enhances the stress distribution which decreases the incidence of root fracture, the most critical form of failure [18–20].

Surface treatments had been suggested to improve the adhesion properties between bi-materials interface, by providing micromechanical and chemical retention between different constituents [21, 22]. Various surface treatments had been applied to enhance the bond strength between the fibre post and other restorative materials as composite core [22] and resin cements [19, 23] including sandblasting, silane coupling agent, and acid etching agents [19, 22–24].

The adhesion between the BD and fiber post was not evaluated. It is important to enhance bonding between BD and fiber post to reinforce the root canal as in cases of non-vital immature permanent teeth. Consequently, the aim of this study was to assess different surface treatments on the push-out bond strength of BD and WMTA to glass fiber posts. The null hypothesis tested was that the surface treatments, type of posts, and type of CSCs would not affect the adhesion between fiber posts and CSCs materials.

Methods

Push-out bond strength

Two brands of glass fiber posts were used: Reblida post (RP; size # Ø 1.5, VOCO, Cuxhaven, Germany) and RelyX post (RX; size # 2, 3M ESPE, St. Paul, MN, USA). Each type of post (n = 40) was divided into four groups (n = 10/group) and exposed to the surface treatment as follows:

Group 1

control (C); no treatment.

Group 2

sandblasting (SB); the specimens were treated with a tribochemical silica-coated (CoJet system; 3M ESPE) with 30 μm aluminum oxide particles at 2.5 bar pressure for 15 s.

Group 3

hydrofluoric acid (HF); the specimens were treated with 9% HF (Ultradent Porcelain Etch, Ultradent Products, South Jordan, UT, USA) for 1 min.

Group 4

TiF_4 4 wt/v% (Aldrich Chemical Company, Milwaukee, WI, USA); the specimens were immersed in TiF_4 4 wt/v% solution for 4 min [23].

The specimens that were treated with HF and TiF_4 4 wt/v% were ultrasonically cleaned in distilled water for 1 min and then air-dried. Each group was further subdivided into two subgroups based on the type of CSCs used as follows:

Subgroup A

BD (Septodont).

Subgroup B

WMTA (PD MTA White; Produits Dentaires SA, Vevey, Switzerland).

A sticky wax was used to position the post perpendicularly on a square plastic plate. Then, the post was surrounded by a cylindrical plastic matrix (10 mm diameter) [22, 24]. The cylinder was filled with the CSCs using a MAP system (MAP One, Produits Dentaires SA, Vevey, Switzerland). The specimens were stored at 37 °C and 100% humidity for 48 h. The specimens were exposed to 10,000 thermocycles in distilled water between 5 and 55 °C with 5-s transfer time and 30-s dwell time [4, 7].

After that, each CSCs-post system was sectioned using a low-speed diamond saw (Isomet 1000, Beuhler Ltd., Lake Bluff, IL, USA) that resulted in 5 discs (n = 50/group). The push-out bond strength of each disc was tested using a universal testing machine (Model TT-B, Instron Co., Canton, MA, USA) and loaded with a cylindrical plunger (1 mm diameter) at 0.05 mm/min cross-head speed. The push-out bond strength (MPa) was calculated by dividing the load at failure (Newtons) by the bonding area (mm^2). The bonding area was calculated using the following equation [22]:

$$A = 2r \times \pi \times h$$

Where r is the post radius, h is the thickness of each post section, and π is the constant 3.14.

Failure Mode Analysis

The debonded specimens were observed by stereomicroscope (ZEISS, Stemi 2000-C, Oberkochen, Germany) at 50 × for analyzing the failure pattern. Failure mode was classified as adhesive, cohesive or mixed.

Surface Topography

A total of 20 specimens of each type of post (n = 5/group) were prepared and grouped as mentioned before. The specimens were sputter-coated with gold (Sputter Coater S 150A; Edwards, Crawley, England). A scanning electron microscope (JSM 5600 Lv JEOL, Tokyo, Japan) was used to characterize the surface topography of the specimens at magnifications of 500×.

Statistical analysis

Data of push-out bond strength were statistically analyzed (SPSS 22.0 software; IBM Corp., Armonk, NY, USA) using three-way ANOVA based on three factors (the type of post, type of treatment, and type of CSCs) and their interactions. Multiple comparisons were conducted by the Tukey's test. The level of statistical significance was set at $P < 0.05$. A Weibull analysis (SuperSMITH software; Fulton Findings, Torrance, CA, USA) was performed on the push-out bond strength data.

Results

The data of push-out bond strength (MPa) are presented in Table 1. The push-out bond strength was significantly influenced by the type of post, type of surface treatment, and type of CSCs ($P < 0.001$). The RP revealed higher bond strength to CSCs than RX ($P < 0.001$). Regarding the type of CSCs, the BD showed higher bond strength than WMTA ($P < 0.001$). There was no significant interaction between type of post and type of CSCs ($P = 0.108$) and between the type of CSCs and type of treatment ($P = 0.394$). There was a significant interaction between the type of post and type of treatment ($P = 0.002$). There was no significant interaction between type of post, type of CSCs, and type of treatment ($P = 0.311$). The push-out bond strength for posts treated with TiF_4 4 wt/v% showed greater bond strength than the other surface treatments ($P < 0.05$). The improvement in the bond strength according to the surface treatments was as follows: TiF_4 4 wt/v% > HF > SB > C. Failure mode analysis of different groups is presented in Fig. 1. The higher percentage of failure modes was the adhesive failure between the post and CSCs (69.5%; Type 1). The other types of failure modes including mixed failures (17.7%; Type 4), cohesive failure within the CSCs (8.9%; Type 3), and cohesive failure within the post (3.9%; Type 2).

Table 1
Mean (Standard Deviation) Values and Statistical Analysis of Push-Out Bond Strength (MPa) of Different CSCs/Post Systems with Different Surface Treatments

Surface treatment	**CSCs/post systems**			
	BD/RP	**BD/RX**	**WMTA/RP**	**WMTA/RX**
C	3.34 (0.78)^{D}	2.73 (0.59)^{D}	2.43 (0.59)^{D}	2.13 (0.46)^{D}
SB	4.38 (1.09)^{C}	3.35 (1.01)^{C}	3.12 (0.49)^{C}	2.65 (0.73)^{C}
HF	5.12 (1.12)^{B}	4.13 (1.11)^{B}	4.23 (0.95)^{B}	3.19 (0.96)^{B}
TiF_4 4 wt/v%	6.15 (1.03)^{A}	5.05 (1.05)^{A}	5.08 (1.05)^{A}	3.99 (0.99)^{A}
Mean values represented with different superscript uppercase letter (column) are significantly different ($P < 0.05$).				

The data of Weibull analysis of different groups are presented in Table 2. The BD/RP-TiF_4 4 wt/v% showed the greater characteristic bond strength (σ_0) (15.93) than the other groups. The surface treatment with TiF_4 4 wt/v% had more reliability than the other treatments (Table 2 and Fig. 2). The Weibull plot for different groups is presented in Fig. 2.

Table 2
Weibull Analysis of Push-Out Bond Strength (MPa) Of Different CSCs/Post Systems with Different Surface Treatments

Surface treatment	CSCs/post systems							
	BD/RP		BD/RX		WMTA/RP		WMTA/RX	
	Weibull modulus (m)	Characteristic bond strength (σ_0)	Weibull modulus (m)	Characteristic bond strength (σ_0)	Weibull modulus (m)	Characteristic bond strength (σ_0)	Weibull modulus (m)	Characteristic bond strength (σ_0)
C	2.63	8.31	3.78	6.5	3.24	6.65	3.15	5.54
SB	2.74	11.41	2.56	8.54	3.87	7.59	4.25	4.31
HF	2.8	12.9	2.53	10.42	3.22	10.86	3.22	5.64
TiF_4 4 wt/v%	3.02	15.93	2.81	12.91	3.89	12.23	3.46	6.77

Representative SEM photomicrographs for the surface microstructure of the different post systems with different treatments are shown in Fig. 3. The untreated RP showed exposed glass fibers with rather a rough surface than RX post that was typically more covered by the resin matrix (Fig. 3A and 3E; respectively). The sandblasted groups exhibited fractured glass fibers (Fig. 3B and 3F; respectively). For the RP post, the HF surface treatment caused cracks in the glass fiber (Fig. 3C). For the RX post, the glass fibers were exposed with HF surface treatment (Fig. 3G). The TiF_4 4 wt/v% surface treatments exposed the glass fibers of the RP and RX posts (Fig. 3D and 3H; respectively).

Discussion

The present study evaluated the effect of surface treatment on bond strength of CSCs materials to fiber posts. The findings showed that the adhesion was considerably affected by the type of post, type of surface treatments, and type of CSCs. Accordingly, the null hypothesis was rejected.

It is significant to enhance bonding between CSCs and fiber posts to reinforce the root canals for treating non-vital immature permanent teeth. All tested groups were subjected to thermocycling to simulate the clinical conditions that might provide a possible prediction of bonding durability [23]. In the present study, TiF_4 4 wt/v% was used because it was shown in a previous study that this concentration enhanced the bond strength of resin cement to a fiber post [23]. Similarly, surface treatment of RP and RX posts with TiF_4 4 wt/v% for 4 min revealed greater bond strength to CSCs than the other treatments. This could be explained that TiF_4 4 wt/v% treatment might remove the surface layer of resin of the post which allows further areas for micromechanical retention with the CSCs [22, 23]. The TiF_4 4 wt/v% surface treatments exposed the glass fibers of the posts (Fig. 3D and 3H; respectively). In addition, surface treatments of fiber posts with TiF_4 4 wt/v% showed higher percentages of mixed failure modes (Type 4) than the other types of surface treatment.

The surface treatment with HF showed higher bond strength of CSCs to fiber posts than SB and C groups. The HF surface treatment might modify the outer surface layer of the fiber post without compromising the strength properties of the post [23, 25]. It was observed that HF surface treatment caused some cracks in RP post and the glass fibers were exposed in RX post (Fig. 3C and 3G; respectively). It was reported that HF surface treatment had a destructive effect on the surface integrity of the fiber post [26, 27]. However, in the present study, HF surface treatment improved the adhesion without an aggressive effect on the fiber posts. This could be explained that different types of posts, method of testing and different tested materials were used compared with the previous studies [26, 27].

Roughening the surface of fiber post with tribochemical silica coating might enhance the bond strength with the other bonded materials due to mechanical retention [23, 28]. Surface roughness with sandblasting increased the surface area of exposed glass fibers for bonding with the CSCs and accordingly enhancing the bond strength [23, 28]. Fiber posts that did not receive surface treatments showed the lowest bond strength with CSCs compared with the other groups. This finding indicates the importance of surface modifications of fiber posts to enhance the adhesion with CSCs.

The RP showed higher bond strength with CSCs than the RX post. This finding could be attributed to the different surface topography between RP and RX posts. The surface topography of RP showed a relatively uneven surface with some uncovered glass fibers as shown in the control group (Fig. 3A) which provides more surface areas for mechanical retention with CSCs. The RP is composed of 70% glass fiber, 10% filler, and 20% urethane dimethacrylate [23]. However, the surface of the RX post was typically more enclosed by the resin matrix (Fig. 3E). The RX post is composed of glass fiber reinforced composite and methacrylate resin [22]. The differences in the composition of posts might influence their bond strength with the CSCs.

The BD revealed higher bond strength with RP and RX posts than WMTA. This enhancement in the bond strength might be due to the improved physical properties and the integrity of BD [5, 29] that might improve the bonding with the glass fiber posts. It had been reported that BD had a higher resistance to dislodgement than WMTA [29]. It could be postulated that BD had better mechanical adhesion with the posts after surface treatment that interlocks mechanically within the surface irregularities. CSCs materials should have adequate adaptation and a consistent adhesion to the post surface to reinforce the roots for treating non-vital immature permanent teeth.

The Weibull analysis was conducted on the push-out bond strength data. The BD/RP-TiF_4 4 wt/v% showed higher characteristic bond strength (σ_0) than the other groups, comparable to the bond strength data. It was observed that TiF_4 4 wt/v% surface treatment had more reliability than the other treatments. It could be postulated that the clinical relevance of fiber post surface treatment with TiF_4 4 wt/v% might improve the bond strength with CSCs. Further *in vivo* studies are essential to assess the performance of treated glass fiber posts with the CSCs to give reliable recommendations for dental practitioners.

Conclusions

BD revealed higher bond strength to fiber posts than WMTA. The TiF_4 4 wt/v% surface treatment enhanced the bond strength of BD and WMTA to glass fiber posts than the other treatments. The RP post improved the bond strength to CSCs than RX posts.

Abbreviations

BD
Biodentine; CSCs:Calcium silicate-based cements; σ_0:Characteristic bond strength; C:Control; HF:hydrofluoric acid; RP:Reblida post; RX:RelyX post; SB:sandblasting; WMTA:white mineral trioxide aggregate

Declarations

Ethics approval and consent to participate

Not Applicable.

Consent for publication

Not Applicable.

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due to (ownership of data) but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported by the Taif University supporting Project number (TURSP-2020/256) Taif University, Taif, Saudi Arabia

Acknowledgements

Not Applicable.

Authors' contributions

AME, SE, AM, AH, and AE were responsible for the concept, design and implementation of the work, analyzed the participant data and interpretation of data. AME and SE were major contributors in writing the manuscript. All authors read and approved the final manuscript.

Author details

1 Department of Endodontics, Faculty of Dentistry, Mansoura University, Mansoura, Egypt

2 Department of Restorative and Dental Materials, Faculty of Dentistry, Taif University, Taif, Saudi Arabia

3 Department of Orthodontic, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia

4 Department of Restorative Science, Vision Colleges, Jeddah, Saudi Arabia

5 Department of Dental Biomaterials, Faculty of Dentistry, Mansoura University, Mansoura, Egypt

References

1. Parirokh M, Torabinejad M: Mineral trioxide aggregate: a comprehensive literature review–Part III: Clinical applications, drawbacks, and mechanism of action. *J Endod.* 2010, 36(3):400–413.
2. Bogen G, Kuttler S: Mineral trioxide aggregate obturation: a review and case series. *J Endod.* 2009, 35(6):777–790.
3. El-Ma'aita AM, Qualtrough AJ, Watts DC: The effect of smear layer on the push-out bond strength of root canal calcium silicate cements. *Dent Mater.* 2013, 29(7):797–803.
4. Elnaghy A, Elsaka S: Fracture resistance of simulated immature roots using Biodentine and fiber post compared with different canal-filling materials under aging conditions. *Clin Oral Investig.* 2020, 24:1333–1338.
5. Grech L, Mallia B, Camilleri J: Investigation of the physical properties of tricalcium silicate cement-based root-end filling materials. *Dent Mater.* 2013, 29(2):e20–28.
6. Küçükkaya Eren S, Aksel H, Askerbeyli Örs S, Serper A, Koçak Y, Ocak M, Çelik HH: Obturation quality of calcium silicate-based cements placed with different techniques in teeth with perforating internal root resorption: a micro-computed tomographic study. *Clin Oral Investig.* 2019, 23(2):805–811.
7. Schmoldt SJ, Kirkpatrick TC, Rutledge RE, Yaccino JM: Reinforcement of simulated immature roots restored with composite resin, mineral trioxide aggregate, gutta-percha, or a fiber post after thermocycling. *J Endod.* 2011, 37(10):1390–1393.
8. Yoldas SE, Bani M, Atabek D, Bodur H: Comparison of the potential discoloration effect of Bioaggregate, Biodentine, and White Mineral Trioxide Aggregate on bovine teeth: In vitro research. *J Endod.* 2016, 42(12):1815–1818.
9. Alazrag MA, Abu-Seida AM, El-Batouty KM, El Ashry SH: Marginal adaptation, solubility and biocompatibility of TheraCal LC compared with MTA-angelus and biodentine as a furcation perforation repair material. *BMC Oral Health.* 2020, 20(1):298.
10. Camilleri J, Formosa L, Damidot D: The setting characteristics of MTA Plus in different environmental conditions. *Int Endod J.* 2013, 46(9):831–840.
11. Kang SH, Shin YS, Lee HS, Kim SO, Shin Y, Jung IY, Song JS: Color changes of teeth after treatment with various mineral trioxide aggregate-based materials: an *ex vivo* study. *J Endod.* 2015, 41(5):737–741.
12. Torabinejad M, Parirokh M: Mineral trioxide aggregate: a comprehensive literature review–part II: leakage and biocompatibility investigations. *J Endod.* 2010, 36(2):190–202.

13. Linsuwanont P, Kulvitit S, Santiwong B: Reinforcement of simulated immature permanent teeth after mineral trioxide aggregate apexification. *J Endod.* 2018, 44(1):163–167.
14. Alonso de la Pena V, Darriba IL, Caserio Valea M, Guitian Rivera F: Mechanical properties related to the microstructure of seven different fiber reinforced composite posts. *J Adv Prosthodont.* 2016, 8(6):433–438.
15. Frater M, Forster A, Jantyik A, Braunitzer G, Nagy K, Grandini S: In vitro fracture resistance of premolar teeth restored with fibre-reinforced composite posts using a single or a multi-post technique. *Aust Endod J.* 2017, 43(1):16–22.
16. Soares CJ, Soares PV, de Freitas Santos-Filho PC, Castro CG, Magalhaes D, Versluis A: The influence of cavity design and glass fiber posts on biomechanical behavior of endodontically treated premolars. *J Endod.* 2008, 34(8):1015–1019.
17. Xie W, Yang S, Hai Q, Wang J: Effect of Ferrule Thickness on Fracture Resistance of Endodontically Treated Incisors Restored with Fiber Post and Metal Crown. *Int J Prosthodont.* 2020, 33(3):321–327.
18. Choi Y, Pae A, Park EJ, Wright RF: The effect of surface treatment of fiber-reinforced posts on adhesion of a resin-based luting agent. *J Prosthet Dent.* 2010, 103(6):362–368.
19. Elnaghy AM, Elsaka SE: Effect of surface treatments on the flexural properties and adhesion of glass fiber-reinforced composite post to self-adhesive luting agent and radicular dentin. *Odontology.* 2016, 104(1):60–67.
20. Arisu HD, Kivanc BH, Saglam BC, Simsek E, Gorgul G: Effect of post-space treatments on the push-out bond strength and failure modes of glass fibre posts. *Aust Endod J.* 2013, 39(1):19–24.
21. Sumitha M, Kothandaraman R, Sekar M: Evaluation of post-surface conditioning to improve interfacial adhesion in post-core restorations. *J Conserv Dent.* 2011, 14(1):28–31.
22. Elsaka SE: Influence of chemical surface treatments on adhesion of fiber posts to composite resin core materials. *Dent Mater.* 2013, 29(5):550–558.
23. Elsaka SE, Elnaghy AM: Bonding durability of titanium tetrafluoride treated glass fiber post with resin cement. *Dent Mater J.* 2019, 38(2):189–195.
24. Goracci C, Raffaelli O, Monticelli F, Balleri B, Bertelli E, Ferrari M: The adhesion between prefabricated FRC posts and composite resin cores: microtensile bond strength with and without post-silanization. *Dent Mater.* 2005, 21(5):437–444.
25. Aksornmuang J, Chuenarrom C, Chittithaworn N: Effects of various etching protocols on the flexural properties and surface topography of fiber-reinforced composite dental posts. *Dent Mater J.* 2017, 36(5):614–621.
26. Valandro LF, Yoshiga S, de Melo RM, Galhano GAP, Mallmann A, Marinho CP, Bottino MA: Microtensile bond strength between a quartz fiber post and a resin cement: effect of post surface conditioning. *J Adhes Dent.* 2006, 8(2):105–111.
27. Sahafi A, Peutzfeld A, Asmussen E, Gotfredsen K: Effect of surface treatment of prefabricated posts on bonding of resin cement. *Oper Dent.* 2004, 29(1):60–68.
28. Cekic-Nagas I, Sukuroglu E, Canay S: Does the surface treatment affect the bond strength of various fibre-post systems to resin-core materials? *J Dent.* 2011, 39(2):171–179.
29. De-Deus G, Ferreira CB, Oliveira Dda S, de Queiroz TF, Souza EM, de Gouvêa CV, Silva EJ: Resistance of hydraulic calcium silicate cements to dislodgment in short- and long-term assessment. *J Adhes Dent.* 2016, 18(2):157–160.

Figures

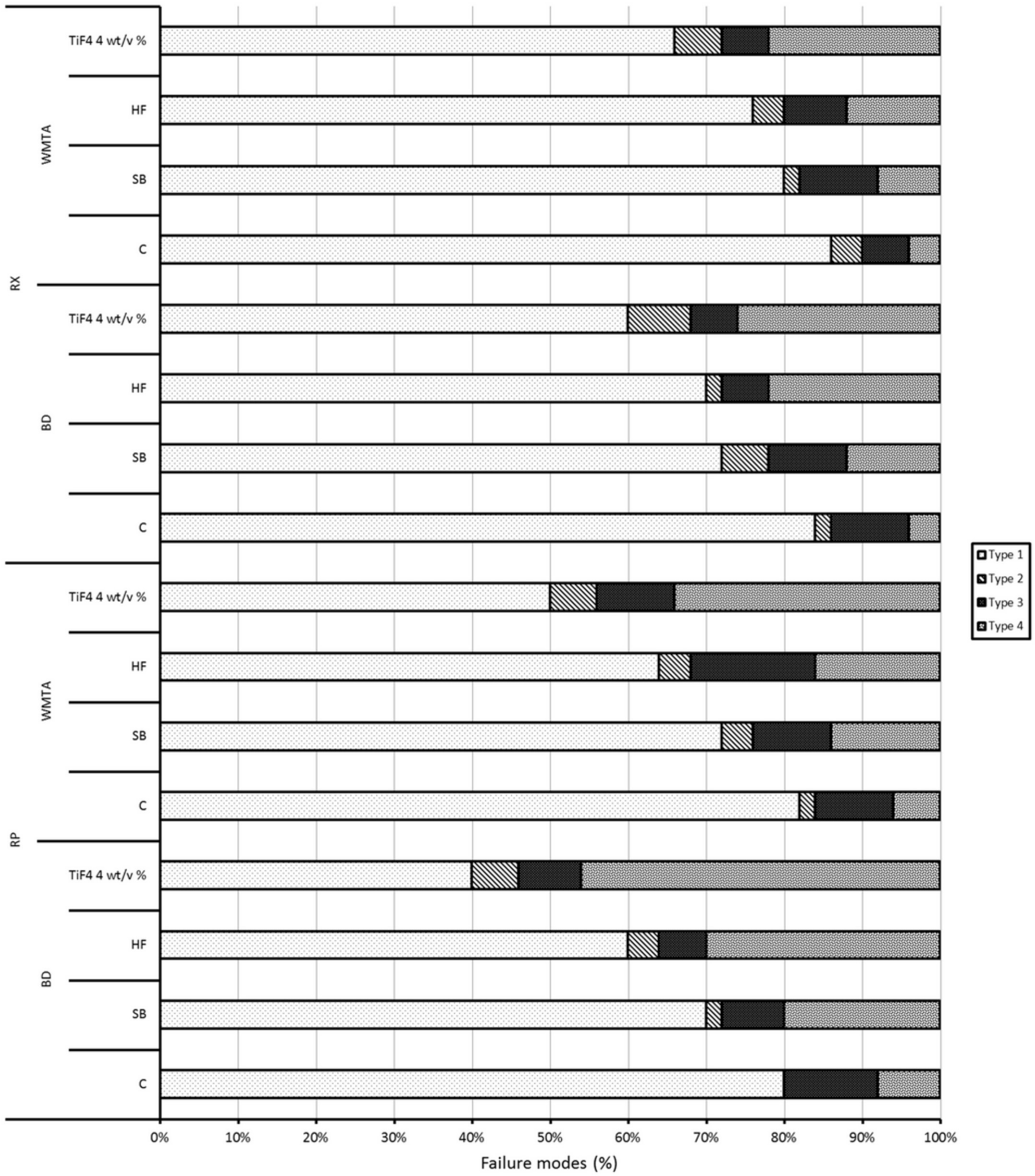

Figure 1

Failure modes distribution of different groups. Type 1; adhesive failure between the CSCs and the post, Type 2; cohesive failure within the post, Type 3; cohesive failure within the CSCs, and Type 4; mixed failure.

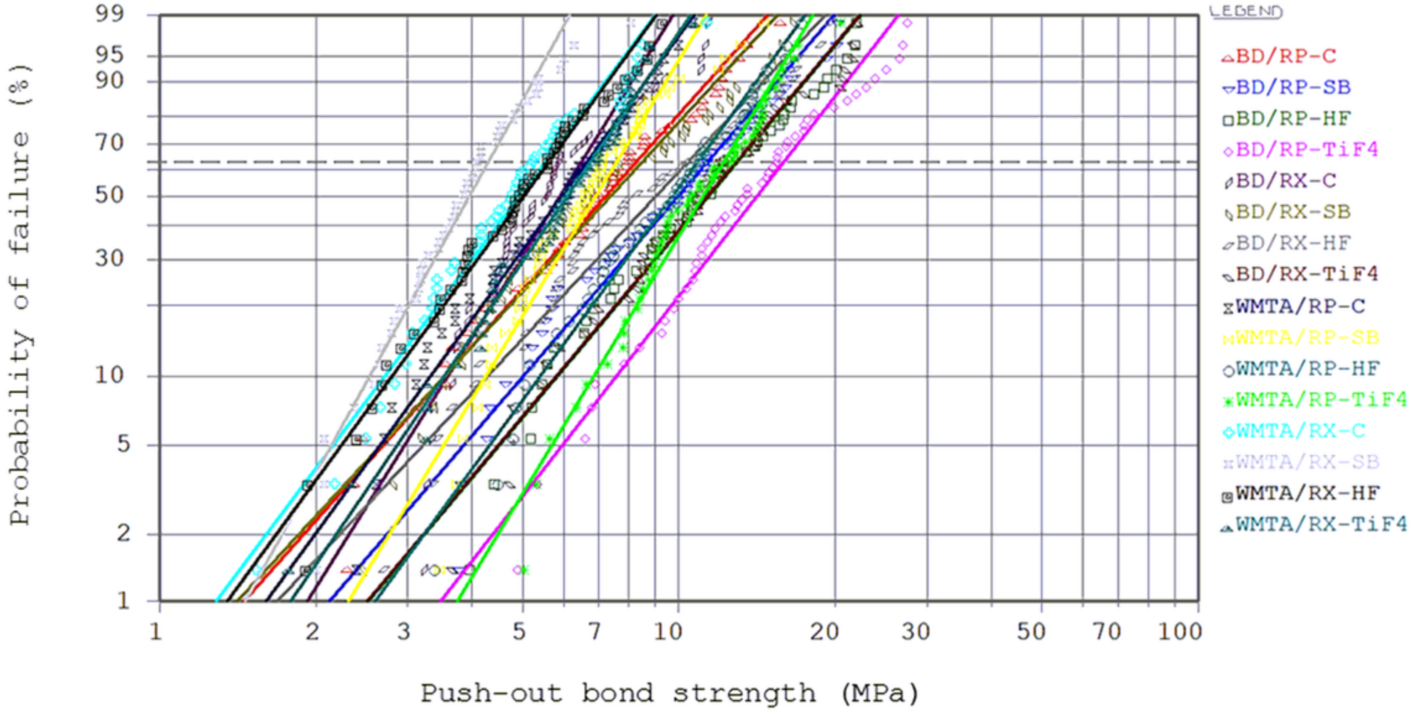

Figure 2

The Weibull plot of push-out bond strength (MPa) for different groups with different surface treatments. The dotted line is the characteristic strength. Surface treatments with TiF4 4 wt/v% showed the highest characteristic bond strength compared with the other surface treatments. The BD/RP-TiF4 4 wt/v% revealed the highest characteristic bond strength compared with the other groups.

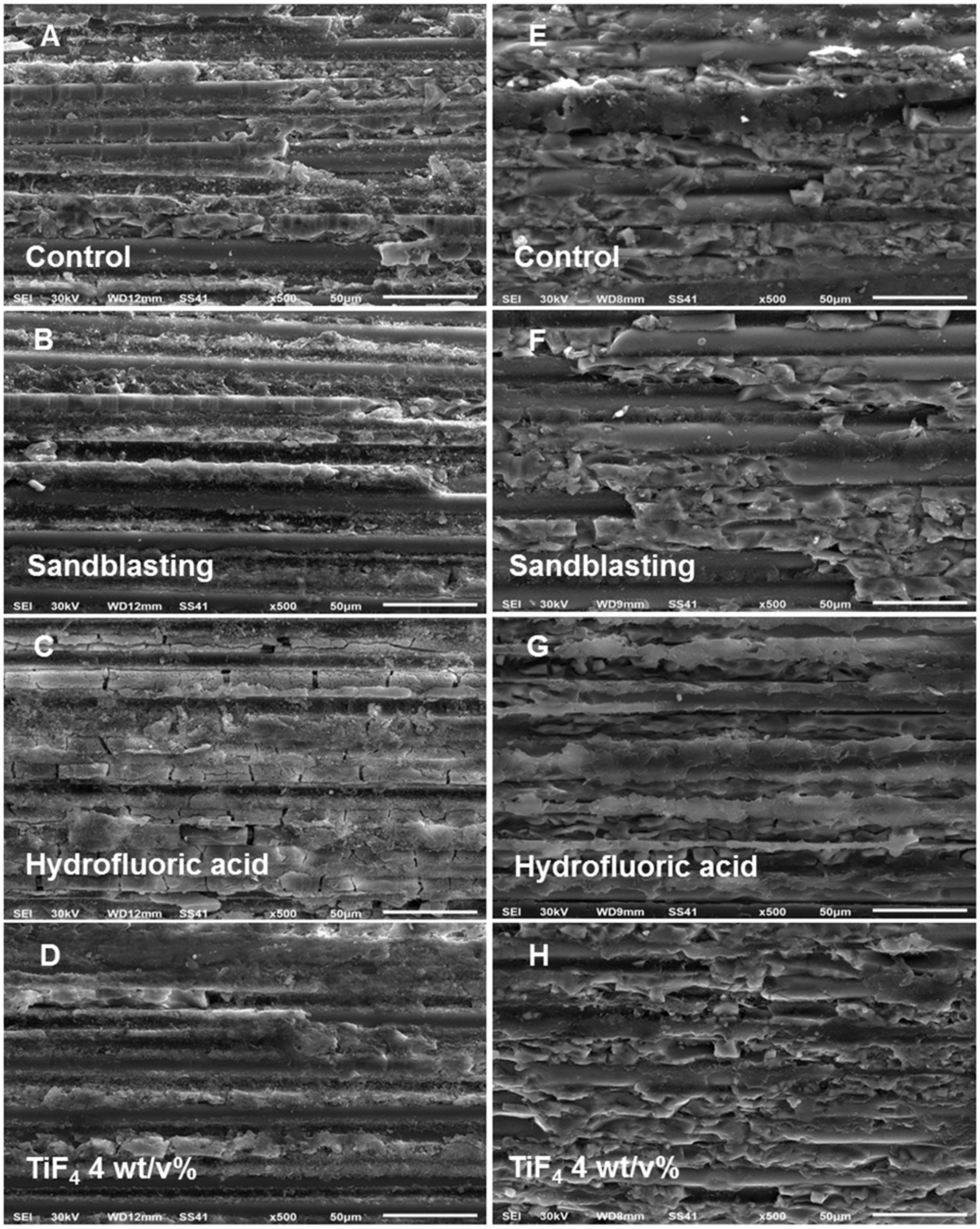

Figure 3

Representative SEM photomicrographs (500×) for the surface microstructure of (A-D) RP and (E-H) RX posts; respectively with different treatments.