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Original Article

Airborne-particle abrasion; searching the right parameter

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Abstract *Background/purpose:* Air-particle abrasion process used to increase surface roughness in order to increase metal-ceramic bond strength varies in each study. This study aims to optimize the air-particle abrasion protocol.
Material and methods: 820 cylindrical nickel-chrome specimens divided equally into 82 groups (n:10). The specimens' s surfaces were air-particle abraded with 50, 110, 250 μm Al_2O_3 at 25, 50,75 psi for 10, 20, 30 s at a distance of 10, 20, 30 mm. To determine the surface roughness, profilometer and atomic force microscope were used. Veneering ceramic was fired onto the specimens and shear bond tests were performed with a universal testing machine. Statistical analyzed were performed using analysis of variance (Kolmogorov–Smirnov).
Results: The difference of surface roughness between all groups were statistically significant ($P < .05$). The highest surface roughness value was measured in 110 μm, 75 psi, 20 mm and 30 s. The higher bond strength values were obtained in 110 μm, 75 psi groups and no statistically significant difference was observed within each group.
Conclusion: While all the air-particle abrasion parameters were effective on surface roughness, only the pressure and grain size make statistically significant difference on shear bond strength.

Introduction

Despite the high esthetic demands of patients, which increases the use of all ceramic restoration systems in prosthetic dentistry,[1,2] metal-ceramic fixed dental prostheses (FDP) are still considered a gold standard treatment option for all oral rehabilitation scenarios due to their superior mechanical properties and their versatility.[3–6]

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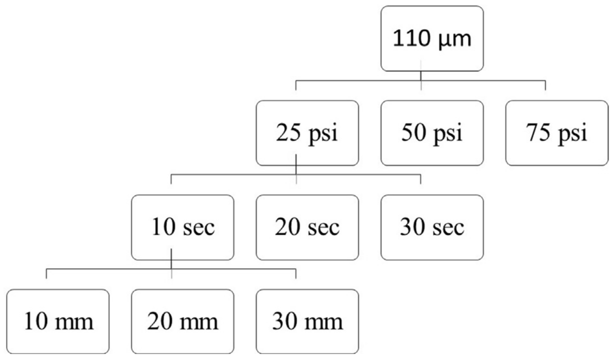

Figure 1 Sandblasting application chart.

Metal-ceramic FDPs have higher mechanical strength,[7–11] and lower ceramic chipping rate compared all-ceramic FDPs.[12] Due to the expensiveness of gold alloys, non-precious metal alloys are preferred in the metal-ceramic restoration process. The most favored non-precious metal alloys are nickel-chromium (Ni-Cr) and chromium-cobalt (Cr-Co).[13]

Despite the excellent clinical performance of metal-ceramic restorations, they exposed excessive force during parafunctional activities, trauma and occlusal alterations that especially break down the metal-ceramic bond on the interface, which plays an important role in function and aesthetics success.

Four mechanisms, chemical bond, mechanical retention, Van der Waal's forces, and compressive forces, affect the metal-ceramic bond strength.[6–11]

Among these mechanisms, airborne-particle abrasion (APA) with Al_2O_3 is mostly commonly used method for providing mechanical retention. This procedure relies upon the particle size of Al_2O_3, the air pressure value of abrasion unit, the distance of sandblaster nozzle from the metal surface and the application time. The APA parameters affecting the metal surface's roughness that influence the metal-ceramic bond strength have been studied in many research with a wide diversity of application but none of them were performed with regard to the all parameters.[1–7] So current research examining whether using the right particle size at the right parameters, aimed to increase surface roughness (SR) and metal-ceramic bond strength is limited.

Therefore, the objective of this study was to compare the effects of particle size, application time, distance of sandblaster nozzle from the metal surface and air pressure of APA on the surface properties of metal substructure and evaluate the effects of obtained SR on metal-ceramic bond strength. The hypothesis was that the highest pressure point of the biggest grain size of Al_2O_3 at the longest time from the nearest distance would result in the highest surface roughness and shear bond strength (SBS).

Materials and methods

A total of 820 non-precious Ni-Cr metal cylinder specimens (System KN, Adentatec GmbH, Köln, Germany), which were 7 mm in diameter, and 10 mm in height, were used directly as provided by the manufacturer. Their smooth surfaces were polished with P0001-220 silicone polisher (NTI silicone, Kerr, CA, USA). 810 specimens were randomly divided into 3 groups ($n = 270$) according to the grain size of Al_2O_3 and then each group divided into 3 subgroups ($n = 90$) according to the applied air pressure values. Each subgroup was divided into additional 9 groups ($n = 10$) corresponding to designated treatment. No surface treatment was performed on control group ($n = 10$).

The APA procedures were performed using a MKK 975 sandblasting machine (Mikrotek dental, Ankara, Turkey). The metal specimens' surfaces were airborne-particle abraded with 50, 110 and 250 µm Al_2O_3 particles

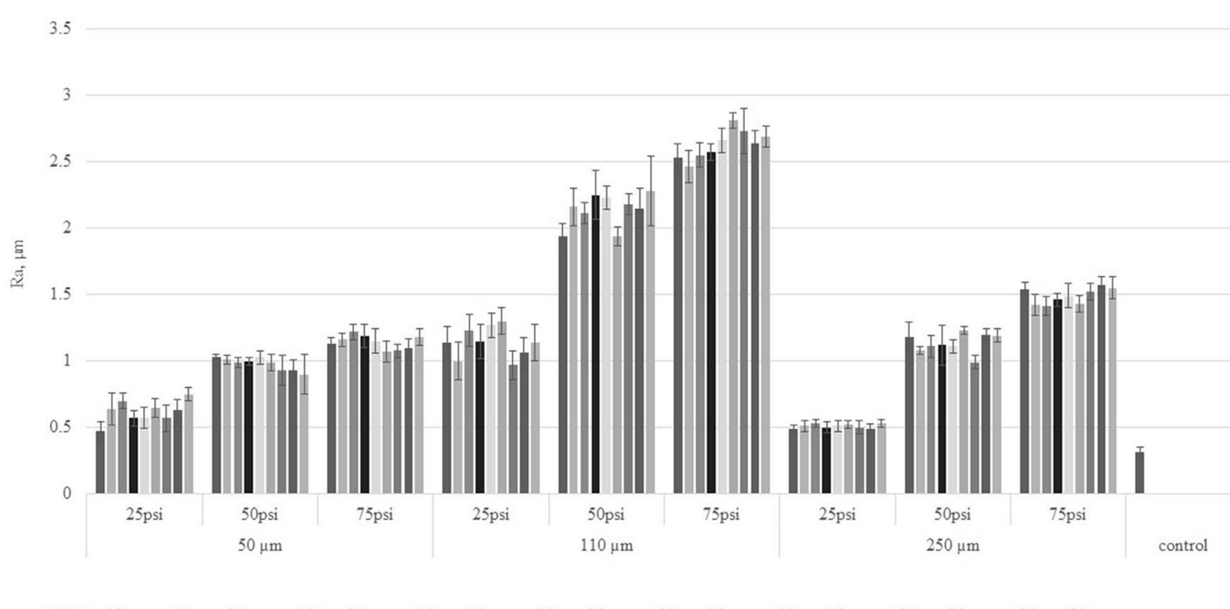

Figure 2 The mean and standard deviations of Ra values of Ni-Cr surface roughness.

(Metoxides, Ankara, Turkey) at 25, 50 and 75 psi from a distance of 10, 20 and 30 mm for 10, 20 and 30 s in the abrasion unit (Fig. 1). The nozzle was positioned vertically above the surface of the specimens by means of a custom-made acrylic model. After APA procedures, the specimens were cleaned ultrasonically with ethanol (Everest ultrasonic, Istanbul, Turkey) for 5 min and then dried at room temperature.

Surface analysis

After the surface treatments, the SR of each specimen was determined with a profilometer (Mitutoyo Surftest SJ-301, Tokyo, Japan). Eight measurements were taken, traveling a distance of 2.5 mm across the abraded surface of each specimen, and the mean value was used to obtain the roughness value (Ra, μm). A higher Ra value indicates a rougher surface.

Atomic force microscopy analysis

The specimens with the highest Ra in the 50, 110, and 250 μm Al_2O_3 abraded groups were examined by atomic force microscopy (AFM), operated in non-contact-mode with a silicon nitride tip (MultiMode, Santa Clara, CA). Images of 15 μm × 15 μm fields were recorded with 0.45 Hz scan rate at 512 × 512 pixels resolution. For each specimen three different areas were measured and the average surface roughness was calculated among them.

Shear bond strength test

Ceramic veneers (Ceramco3, Dentsply, Hanau-Wolfgang, Germany) were applied by using a custom-made metal mold (5 mm diameter and 3 mm thickness) onto metal specimens' surfaces and fired at 950 °C in a vacuum furnace according to the manufacturer' s instruction. All specimens were immersed in water at 37 °C for 24 h. Then, SBS measurements were performed using a universal testing machine (Lloyd LF Plus, Ametek, UK) with a 1 mm/min crosshead speed was used.

Statistical analysis

Statistical analysis was performed with SPSS 15.0 software (SPSS Inc., Chicago, IL). The data were analyzed with analysis of variance (Kolmogorov—Smirnov), Tukey test with statistical significance set at the 0.05 probability level.

Results

The mean SR values of airborne-particle abraded specimens were presented in Fig. 2 and Table 1. The selected specimens' AFM images were depicted in Fig. 3. The Ra values of SR for all metal specimens were significantly increased in all APA groups when compared with control group ($P < 0.05$). Particle size, air pressure, application time, and the distance of nozzle yielded effects on the roughness. Regarding the particle size of Al_2O_3, the 110 μm abraded groups presented the highest SR values ($P < 0.05$) and

Table 1 The mean Ra and standard deviation of surface roughness.

	50 μm			110 μm			250 μm		
	25 psi	50 psi	75 psi	25 psi	50 psi	75 psi	25 psi	50 psi	75 psi
10 mm 10 s	0.47 ± 0.07	1.03 ± 0.02	1.13 ± 0.05	1.14 ± 0.12	1.94 ± 0.09	2.53 ± 0.10	0.49 ± 0.03	1.18 ± 0.11	1.54 ± 0.05
10 mm 20 s	0.64 ± 0.12	1.01 ± 0.03	1.16 ± 0.05	1.00 ± 0.14	2.16 ± 0.14	2.46 ± 0.12	0.51 ± 0.04	1.08 ± 0.03	1.42 ± 0.08
10 mm 30 s	0.70 ± 0.06	0.99 ± 0.04	1.22 ± 0.06	1.23 ± 0.12	2.11 ± 0.08	2.55 ± 0.09	0.53 ± 0.03	1.11 ± 0.08	1.41 ± 0.07
20 mm 10 s	0.57 ± 0.06	1.00 ± 0.03	1.19 ± 0.09	1.15 ± 0.13	2.25 ± 0.18	2.57 ± 0.06	0.50 ± 0.04	1.12 ± 0.15	1.46 ± 0.05
20 mm 20 s	0.57 ± 0.08	1.03 ± 0.05	1.15 ± 0.09	1.27 ± 0.09	2.23 ± 0.09	2.66 ± 0.09	0.51 ± 0.04	1.11 ± 0.05	1.49 ± 0.09
20 mm 30 s	0.65 ± 0.07	0.99 ± 0.06	1.07 ± 0.08	1.30 ± 0.10	1.94 ± 0.07	2.81 ± 0.06	0.52 ± 0.03	1.23 ± 0.03	1.43 ± 0.06
30 mm 10 s	0.57 ± 0.10	0.93 ± 0.11	1.08 ± 0.05	0.97 ± 0.11	2.18 ± 0.08	2.73 ± 0.17	0.50 ± 0.05	0.99 ± 0.05	1.52 ± 0.06
30 mm 20 s	0.63 ± 0.08	0.93 ± 0.08	1.10 ± 0.07	1.06 ± 0.12	2.15 ± 0.15	2.64 ± 0.09	0.49 ± 0.04	1.20 ± 0.04	1.57 ± 0.06
30 mm 30 s	0.75 ± 0.05	0.90 ± 0.15	1.18 ± 0.06	1.14 ± 0.14	2.28 ± 0.26	2.69 ± 0.08	0.53 ± 0.03	1.19 ± 0.05	1.55 ± 0.08
	F = 7.45	*F* = 2.78	*F* = 4.13	*F* = 11.55	*F* = 5.10	*F* = 8.59	*F* = 0.95	*F* = 7.00	*F* = 5.38
	P = .001	*P* = .010	*P* = .001	*P* = .001	*P* = .001	*P* = .001	*P* = .448	*P* = .001	*P* = .001

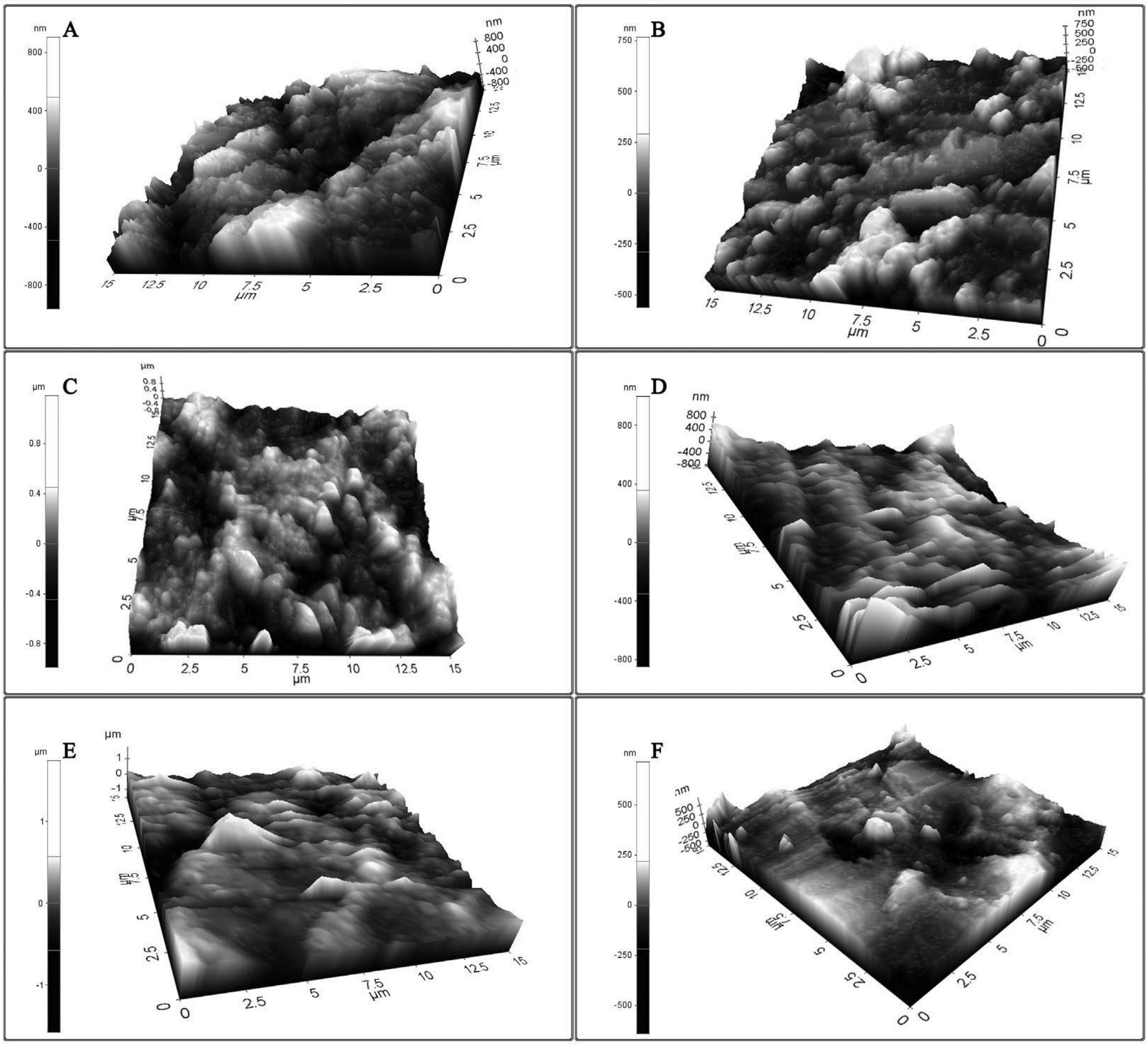

Figure 3 AFM images A) 50 μm/75 psi/10 mm/30 s B) 50 μm/50 psi/10 mm/10 s C) 110 μm/75 psi/20 mm/30 s D) 110 μm/50 psi/30mm/20 s E) 250 μm/50 psi/20 mm/30 s F) 250 μm/75 psi/30 mm/20 s.

significantly higher ($P < 0.05$) SR values were obtained with 75 psi pressure.

When the results of 110 μm/75 psi group were evaluated, the application time had only statistically significant effect on the SR of the 20 mm groups and it was found that it enhanced with increasing time. Concerning the application distance, the results showed that there was an increase in the mean Ra values as the distance increased. Only the application from the 20 mm distance was found more effective than 30 mm in 30 s group (Table 2). According to these findings the most effective parameter combination on SR was found 110 μm 75 psi 20 mm 30 s ($P < 0.05$).

The mean SBS values were depicted in Table 3 and Fig. 4. The statistical analysis revealed significant differences between all groups, except 50 μm Al_2O_3 groups. The highest bond strength values were obtained in 110 μm/75 psi groups and the changes in application time and application distance did not make any significant difference in metal-ceramic bond strength.

Table 2 The mean Ra values of 110 μm/75 psi groups.

	10 s	20 s	30 s	
10 mm	2.53^{a}	$2.46^{c,d}$	2.55^{e}	*P* > *0.005*
20 mm	$2.57^{x,b}$	2.66^{c}	$2.81^{x,e}$	^{x} *P*<*0.005*
30 mm	$2.73^{a,b}$	2.64^{d}	2.69^{e}	*P* > *0.005*

a, b $p < 0.05$.
c, d $p < 0.05$.
e $p < 0.05$.
* same letters mean significant difference between each other ($P < .05$).

Discussion

Airborne-particle abrasion procedure applied to the metal surface in order to enhance the metal-ceramic bond strength increases the contact surface area of metal and

Table 3 The mean SBS and standard deviation values.

	50 μm			110 μm			250 μm		
	25 psi	50 psi	75 psi	25 psi	50 psi	75 psi	25 psi	50 psi	75 psi
10 mm 10 s	12,3 ± 1,6	12,1 ± 2,34	12,11 ± 1,59	15,24 ± 2,07	18,18 ± 3,09	18,74 ± 1,23	8,72 ± 1,27	15,62 ± 2,21	16,84 ± 1,66
10 mm 20 s	12,6 ± 1,17	12,46 ± 2,6	12,6 ± 1,22	15,33 ± 1,1	18,23 ± 2,03	18,45 ± 1,31	8,21 ± 1,62	15,42 ± 2,16	16,76 ± 1,31
10 mm 30 s	12,48 ± 1,9	12,38 ± 1,55	12,43 ± 1,21	15,43 ± 2,03	18,41 ± 2,14	18,75 ± 1,21	8,37 ± 1,77	15,9 ± 2,33	17,28 ± 1,45
20 mm 10 s	11,79 ± 1,65	11,77 ± 1,42	12,04 ± 1,67	15,28 ± 2,04	18,31 ± 2,24	18,73 ± 2,18	8,54 ± 1,4	16,19 ± 2,45	16,66 ± 1,44
20 mm 20 s	12,36 ± 1,17	12,39 ± 1,2	12,16 ± 1,56	15,57 ± 1,23	18,55 ± 2,26	19,95 ± 2,4	8,69 ± 1,21	16,5 ± 2,02	16,88 ± 1,57
20 mm 30s	12,18 ± 1,62	12 ± 2,47	12,76 ± 1,15	15,21 ± 2,04	18,5 ± 2,22	19,28 ± 2,41	8,35 ± 1,37	16,15 ± 2,41	16,45 ± 2,24
30 mm 10 s	12,63 ± 1,2	12,2 ± 2,51	12,69 ± 1,16	15,41 ± 2,12	18,16 ± 2,16	18,23 ± 2,39	8,06 ± 1,18	15,91 ± 2,06	16,71 ± 2,29
30 mm 20 s	12,48 ± 1,29	12 ± 2,4	12,53 ± 1,24	15,56 ± 2,27	18,37 ± 2,39	19,52 ± 2,45	8,45 ± 1,71	15,81 ± 2,45	16,73 ± 2,15
30 mm 30 s	12,69 ± 1,23	12,5 ± 3,09	12,78 ± 1,13	15,39 ± 1,08	18,41 ± 2,19	19,5 ± 3,54	8,92 ± 1,37	16,17 ± 2,4	17,08 ± 2,4
	F = 1,92	*F* = 1.024	*F* = 1.063	*F* = 2.56	*F* = 1.158	*F* = 1.735	*F* = .938	*F* = 1.471	*F* = .973
	P = .097	*P* = .442	*P* = .154	*P* = .182	*P* = .359	*P* = .237	*P* = .503	*P* = .214	*P* = .478

ceramic. Although the importance of this process has been emphasized in many studies, the used parameters vary in each study.[14,15] This study aimed to determine the optimal combination of all parameters that could be used in APA. The results obtained in this research indicated that the increase in the particle size of Al_2O_3 did not create directly proportional SR and SBS; however, the increased pressure values increased the roughness and bond strength. It was determined that the distance and application time changes were effective on surface roughness, however they had no distinguishing influence on bond strength. Thus, the hypothesis suggested at the beginning is partially supported by the results.

The metal we preferred in this study was Ni-Cr which is known to cause an allergic reaction in 0,1—0,2% of the population.[16] We made this decision according to the results of the study conducted by Sipahi et al.[17] in which they evaluated the bond strength between different metal alloys and different ceramics. In their study, they stated that the metal-ceramic bond strength was independent from metal type, but they also emphasized that the greatest bond strength value was detected in Ni-Cr alloys. Although other studies[11,18,19] on the same subject declared both similar and different results, Sipahi's study was used as a reference due to their consistent data when compared to the high standard deviations in the results of other studies.

The hardness of the metal is another parameter that affects the roughness value in APA procedures. Hardness values of metals which have the same ingredient show varieties according to the manufacturers. While Wiron 99 manufactured by Bego, Starley N by Degudent and System KN by Adentatec are Ni-Cr group metals and their hardness values are approximately 185 VH,[20—22] 4all manufactured by Ivoclarvivadent has harder (235 VH) structure.[23] This variance may cause differences in effective parameters applied in APA procedures. Accordingly, we preferred the material with the most common hardness value in this study. Furthermore, the preference of the range of the APA parameters were based on the previous publications[8,9,17] and manufacturer's instruction.[20]

This study indicated that there was a significant increase in SR and SBS value after the airborne-particle abrasion procedure was applied with the right parameters. The SR of the metal increases the mechanical retention, which is a significant factor for achieving a sufficient metal-ceramic bond strength.[24] Moreover, APA also influences the thickness of the oxide layer of metal surface which directly effects the bond strength between metal and ceramic. It was indicated that the thinner the oxide layer prepared on the metal surface is the stronger the metal-ceramic bond strength.[25] The data obtained shows that the application duration, the pressure, and the distance are as important as the particle size of the Al_2O_3.

In APA procedures, among the applied pressure values the lowest Ra values were always obtained at 25 psi. Furthermore, there was an increase in the SR in direct proportion to the increase in the pressure level. This was due to the enhancement in the amount of the Al_2O_3 coming out of the nozzle because of the increasing pressure. Similarly, the results showed that there was an increase in the SR as the applied distance increased and this could be

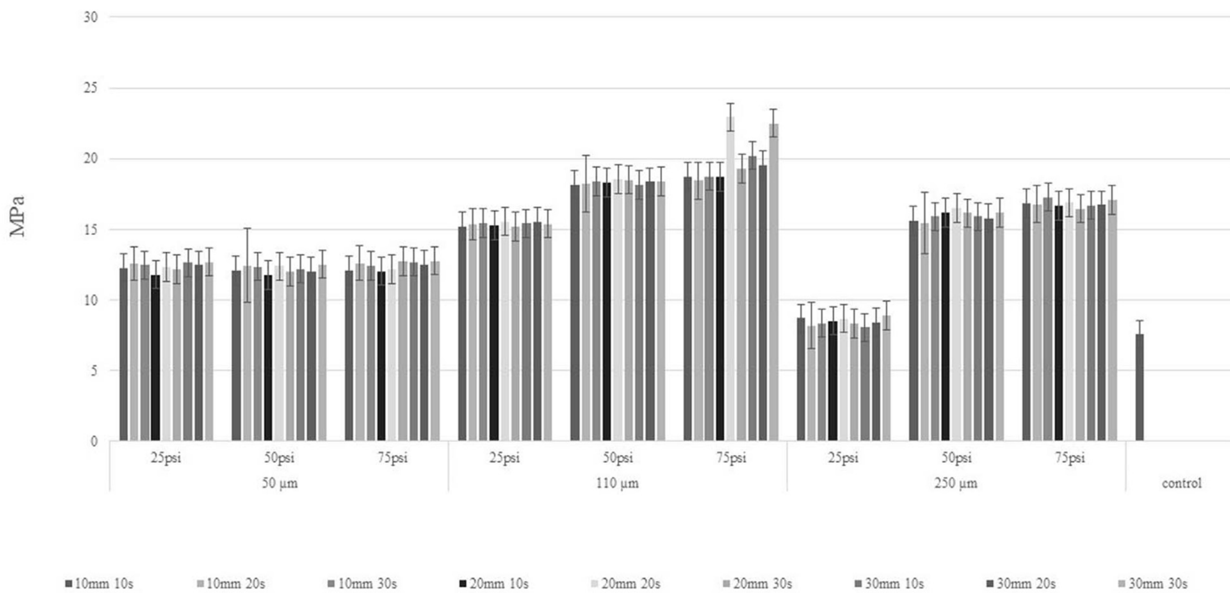

Figure 4 The mean and standard deviations of SBS values (MPa).

explained by the effect of gravity on the acceleration of the sand speed.

Based on the results of measurements, the SR values were independent from the application time. In this study, 3 different time periods were chosen for the application and the results showed that there was no significant difference in roughness values when applied over 10 s. The exceptions were thought to be due to the limitations that occurred in the measurements.

When the data obtained in this study were evaluated only in terms of particle size, the SR increase was not parallel to the increase in particle size. While the SR obtained with 250 μm was higher than 50 μm, it was lower compared to the values obtained with 110 μm. Such a result can be explained that the increased size of Al_2O_3 causes a decreased flow volume of sand particles from the nozzle, while decreasing size diminishes the effect of Al_2O_3 on the metal surface. Concerning the particle size, the results of this study were consistent with Külünk et al.[9] who used 50 and 110 μm Al_2O_3 to find out the effect of APA on metal-ceramic bond strength and reported that the increased bond strength was achieved with 110 μm Al_2O_3.

Two different devices, AFM and profilometer were used to determine the effectiveness of different parameters of APA on SR. AFM is able to take images from smaller areas with atomic resolution, however profilometer scans the larger field so as to get consistent result, which represent the whole surface.[26] In this study scanning of a wider area especially in the measurement of short-time duration application, is more important. Profilometer is thought to be more consistent in terms of obtaining the data, since the images of AFM did not seem to support neither the SR nor the SBS values truly. For instance, the image E and F depicted in Fig. 3 represent the 250 μm 50 psi and 250 μm 75 psi, were detected more roughly than the image A and B, the 50 μm groups, in profilometer however they appeared to be smoother in AFM images. Besides, in contrast to the AFM images, the profilometer results supported by the SBS data.

There is no doubt on the consensus about the requirement of the surface treatment to get adequate bond strength between metal and ceramic.[27,28] Many authors have emphasized the effectiveness of APA for roughening, however there is no agreement on the applied parameters. Some authors[11,29] disregarded the hardness values of different types of metal when analyzing the bond strength between metal and ceramic, and roughened all types of metal with 50 μm Al_2O_3 without providing any information on other parameters, while others[30,31] chose specific parameters of pressure, distance, particle size, and time without any reference. De melo et al.[18] evaluated the shear bond strength between ceramic and 4 different alloys. They used 100 μm Al_2O_3 at 2 bar for 10 s at a 20 mm distance for APA of Ni-Cr and Co-Cr. They mentioned that none of the metals shows higher bond strength to the porcelain tested. Furthermore, Amara et al.[8] investigated the effect of metal type and surface treatment on tensile strength. They used 50 μm Al_2O_3 at 70 psi for 10 s at a distance of 10 mm and reported that there was no difference between metal types and surface treatment methods.

Akova et al.[19] evaluated the shear bond strengths of cast Ni—Cr, Co—Cr, and the laser-sintered Co—Cr alloys and ceramic. The metal surfaces were abraded with 150 μm Al_2O_3 at 6 atm for 10 s at a 10 mm distance. They concluded that the bond strength was higher for the Ni-Cr alloys but no significant difference was detected between groups. Ucar et al.[32] investigated the effect of numerous castings on shear bond strength of Ni-Cr alloy and ceramic and declared that fully fresh group had higher bond strength. In this study, APA was performed with Al_2O_3 for 10 s at 6 bar at a distance of 20 mm, however particle size was not mentioned.

Although all these studies were carried out in different fields, the common point is that they all obtained $\geq$25 MPa bond strength, which is considered to be an adequate bond strength according to the ISO 9693, despite the use of different parameters without referring. In the present study, the obtained metal-ceramic SBS values vary between 8.09 and 19.95 MPa, depending on the particle size of Al_2O_3 and the air pressure. The higher SBS values of these studies may be attributed to the application of APA procedure after deflasking the casts. Furthermore, these studies were on the subject of metal-ceramic bond strength, they provided no information on the obtained roughness values. However, our methodology was similar to the study performed by Nergis et al.[33] that casted specimens were used after polishing in order to get uniform surface, and after the applying different surface treatments, roughness values were measured. They mentioned that the obtained shear bond strengths were <25 MPa in all groups, which were similar to ours.

With the limitations of the study, we concluded that airborne-particle abrasion with Al_2O_3 at 75 psi for 30 s with 110 μm at a distance of 20 mm is suggested for achieving an increased surface roughness of Ni-Cr alloys. However, the changes in the application time and the distance did not make any statistically significant difference on shear bond strength between metal and ceramic. Furthermore, all these APA parameters must be adjusted for different kinds of metal alloys.

Conflicts of interest

All authors have no conflicts of interest to declare.

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