

# Research on the Role of Surface Treatment of the Metal Surface on the Strength of the Metal–Ceramic Bond

Georgia Asproudi<sup>1</sup>, Panagiotis Galiatsatos<sup>2</sup>, Aristidis Galiatsatos<sup>3</sup>

## ABSTRACT

**Aim:** The aim of the present study is to investigate the metal–ceramic bond strength as a result of three different surface treatment methods: (1) oxidation, (2) oxidation and sandblasting, and (3) double oxidation on the metal substrate.

**Materials and methods:** A total of 72 metal substrates were made from two different types of metal–ceramic alloys ( $n = 36$ ): group I, Ni–Cr and group II, Co–Cr alloys. Each group was further divided and subjected to three different surface treatments ( $n = 12$ ): (1) oxidation in accordance with the manufacturer's instructions; (2) oxidation according to the manufacturer's instructions and then sandblasting with  $Al_2O_3$ , with a grain size of 110  $\mu m$ , a pressure of 75 psi for 10 sec with a distance of 5 cm and steam cleaning; and (3) double oxidation. The bond strength of the specimens was evaluated with the three-point bending process. The data were recorded, tabulated, and statistically analyzed.

**Results:** For group I, the materials with oxidation based on the specifications, show mean value of 64.02 Nt. The oxidation and sandblasting materials have mean 55.92 Nt. The double oxidation materials have mean 55.47. For group II, the materials with oxidation based on the specifications, show mean value of 58.46 Nt. The oxidation and sandblasting materials have a mean value of 42.56 Nt. The double oxidation materials have mean 42.96 Nt.

**Conclusion:** The best method of treatment of the metal substrate is specification oxidation, in terms of the strength of the metal–ceramic bond. Further treatment of the metal substrate reduces the strength of the metal–ceramic bond.

**Clinical significance:** A prerequisite for clinical success of metal–ceramic prosthetic restorations is the increased strength of the bond between ceramic material and metal substrate. With that in mind, the present research gives important insight into best practices for prosthetic restorations.

**Keywords:** Co–Cr alloy, Metal–ceramic bond, Metal substrate, Ni–Cr alloy, Surface treatment.

*The Journal of Contemporary Dental Practice* (2023): 10.5005/jp-journals-10024-3492

## INTRODUCTION

Metal–ceramic prosthetic restorations have been used for several decades in clinical practice with survival rates of up to 90% for the period of 10–15 years, because of their biocompatibility and esthetics, which are deemed superior to the alternatives.<sup>1–6</sup>

The strength of these restorations is an important factor for their survival in the dynamically changing oral environment (temperature change, pH change, chemical changes), and even under the application of intense and alternating loads. In particular, the forces developed on dental restorations during the application of masticatory loads are complex (tensile forces, shear forces, lateral forces).<sup>7–10</sup> Thus, the choice of the appropriate material and the appropriate technique of fabrication of metal–ceramic restoration is one of the main factors that will ensure their protection against fracture.<sup>10–15</sup>

Also critical to the clinical longevity of these restorations is the achievement of a satisfactory bond between the alloy and the ceramic material. The treatment of the metal framework prior to the porcelain build-up during the fabrication of these restorations has been shown to be a key step that plays an important role in the strength of the metal–ceramic bond.<sup>11–18</sup> It is commonly discussed that when metal surfaces are prepared before applying porcelain, the porcelain clings more securely to the metal and the strength of the metal–ceramic bond is increased. Usually, a degassing technique or metal coating is used to condition the metal. Regarding the exact preparation of metals for ceramic bonding, opinions continue to vary, however.<sup>1–3</sup>

Various methods of treatment of the metal substrate prior to porcelain construction have been proposed from time to

<sup>1</sup>Athens, Greece

<sup>2</sup>Department of Prosthodontics, School of Dentistry, National and Kapodistrian University of Athens, Athens, Greece

<sup>3</sup>Division of Dental Technology, Department of Biomedical Sciences, University of West Attica, Athens, Greece

**Corresponding Author:** Georgia Asproudi, 21 Mandilara Nikiforou Str., Egaleo, Athens, Greece, e-mail: gasproudi26@hotmail.com

**How to cite this article:** Asproudi G, Galiatsatos P, Galiatsatos A. Research on the Role of Surface Treatment of the Metal Surface on the Strength of the Metal–ceramic Bond. *J Contemp Dent Pract* 2023;24(3):188–194.

**Source of support:** Nil

**Conflict of interest:** None

time, such as (a) specification-based oxidation, (b) sandblasting, (c) specification-based oxidation and sandblasting, (d) vacuum oxidation, and (e) double oxidation.<sup>14–26</sup>

The aim of the present study is to investigate the metal–ceramic bond strength as a result of three different surface treatment methods of the metal substrate. These three methods are (1) oxidation according to the manufacturer's instructions (the metal is subjected to oxidation heat treatment, which includes degassing, outgassing, and preoxidation. This process cleans the metal's surface of impurities and forms the metal oxide coating); (2) oxidation and sandblasting (cleaning and roughening components' surfaces using the force of a high-speed sand flow); and (3) double oxidation on the metal substrate (oxidation, sandblasting, steam cleaning and oxidation again).

**Table 1:** Composition of alloys

Element (wt%)	Ni	Cr	Mo	Si	Co	W	Fe	Ce	C
Keralloy	61.4	25.9	11.0	1.5	-	-	-	-	-
N supreme alloy									
Wirobond	-	26.0	6	1	61	5	0.5	0.5	Max 0.05
C alloy									

The null working hypothesis is that the various treatment methods of the metal surface do not affect the strength of the metal–ceramic bond.

**MATERIALS AND METHODS**

All the research tests were carried out in the Biomaterials Laboratory of the School of Dentistry of the University of Athens. A total of 72 metal–ceramic specimens wherein 36 comprised group I: Ni–Cr alloy (Keralloy N Supreme, Siladent Co, Germany) and group II: 36 of Co–Cr alloy (Wirobond C, Bego Co, Bremen, Germany) were fabricated according to the EN ISO 9693 specification, with specific dimensions of  $0.5 \pm 0.05$  mm thickness,  $3 \pm 0.1$  mm width, and  $25 \pm 1$  mm length.<sup>14</sup> After fabrication, an X-ray inspection (gamma radiation intensity; 60 kV and 7.10 mAs) was performed to determine the internal porosity. The metallic porous substrates if confirmed were remanufactured and X-ray retested to meet the required sample size of the study. Table 1 represents the chemical composition of the alloys considered.

Thirty-six specimens of each group were further divided into three groups ( $n = 12$ ) based on the specific surface treatments before the application of ceramic material in the methodology.

Group A: Corrosion according to the manufacturer’s guide.

Group B: Oxidation according to the manufacturer’s instructions followed by sandblasting with  $Al_2O_3$ , grain size 110  $\mu m$ , pressure 75 psi for 10 sec at a distance of 5 cm and cleaning with steam.

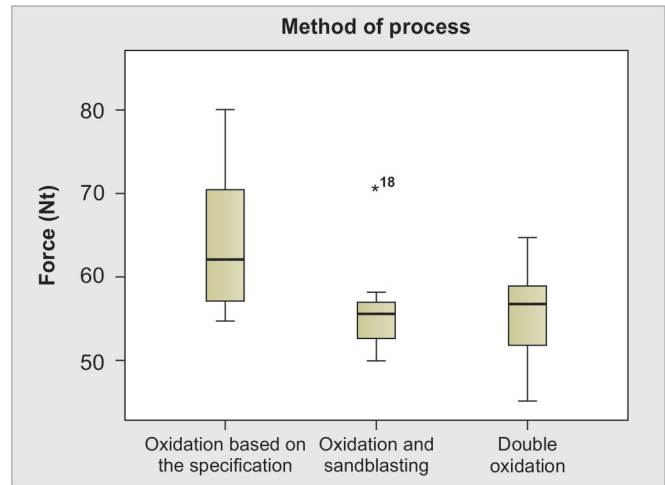
Group C: Double oxidation, i.e., oxidation, sandblasting with  $Al_2O_3$ , grain size 110  $\mu m$ , pressure, 75 psi for 10 sec with a distance of 5 cm, steam cleaning and oxidation again in the same cycle as the original.

The ceramic mass was placed on the metal substrates in the dental laboratory, following the manufacturer’s instructions. The coating of the ceramic material (Ex – 3, Noritake Co, Japan) was applied at a thickness of  $1.1 \pm 0.1$  mm, a width of  $3 \pm 0.1$  mm, and a length of  $8 \pm 0.1$  mm, according to the EN ISO 9693 specification.<sup>14</sup>

The metal–ceramic specimens were then subjected to thermal cycling: 3000 cycles between  $500 C \pm 1$  and  $550 C \pm 1^\circ C$  in distilled water. The residence time at each temperature was 10 sec, while the time to transfer the specimens from one water bath to another was 5 sec.

The 72 metal–ceramic specimens (36 of group I and 36 of group II) were subjected to a three-point bending test to determine the strength of the metal–ceramic bond using a mechanical testing apparatus (Tensiometer 10, Monsanto, Akron, Ohio, USA). The test was carried out in the Biomaterials Laboratory of the School of Dentistry of the University of Athens. A force/load was applied to the specimens at the center, with a head displacement rate of  $1.5 \pm 0.5$  mm/min. The failure of the metal–ceramic bond was perceived by a sudden decrease in the stress and strain curve. Thus, the load at which the failure of the metal–ceramic bond was observed was recorded. The strength of the metal–ceramic bond in units of MPa was calculated on the basis of the relationship:

$$\text{Bond strength} = F_{\text{fail}} \cdot k$$



**Fig. 1:** Overall results of group I (Ni–Cr)

where  $F_{\text{fail}}$  is the load at which failure was observed or otherwise the failure force ( $N_t$ ) and  $k$  is a coefficient defined by EN ISO 9693 which ranges from  $0.5 \pm 0.05$  of the metal substrate and on the young’s modulus of the alloy.<sup>14</sup>

Fracture surfaces were examined using optical microscopy (Leica M-80 DFC 295, Leica Microsystems GmbH, Germany) to determine the mode of failure based on the fracture origin (adhesive fracture, adhesive/cohesive fracture, cohesive fracture). The obtained results were statistically analyzed by analysis of variance (ANOVA) at a 0.05 significance level with the use of SPSS software.

**RESULTS**

Results of Optical Microscope for Group Ni–Cr Alloy (Group I).

All specimens in all subgroups exhibited cohesive failure. Inspection of the specimens under the optical microscope showed the persistence, on the fractured metal surfaces, of elements. These most likely represent elements of the adhesive and ceramic mass.

Total Results for Group I (Ni–Cr Alloy).

A scorecard showing the overall results of Group I can be found in Figure 1.

Statistically significant differences are observed in group I by distinguishing the results according to the three treatment methods applied to the materials.

The materials with oxidation based on the specifications, show mean 64.02 Nt.

The oxidation and sandblasting materials have mean 55.92 Nt. The double oxidation materials have mean 55.47 Nt.

It was noticed that between all three methods there are no significant differences in the mean value but in the range of bending values. Similarly, the specification-based oxidation shows significant differences in addition to the other two processing methods.

The oxidation and sandblasting method, despite its low range of values, seems to have the highest concentration and, despite the limited range, enables the craftsman to have more concentrated strength values of the material.

Similarly, specification-based oxidation gives a wider range of values which means that it is more difficult for the craftsman to determine the range of values that the material can withstand and accordingly to advise the customer on the care he should take with the pressures he applies to the material. Similarly, double oxidation shows the lowest strength values of the other two groups.

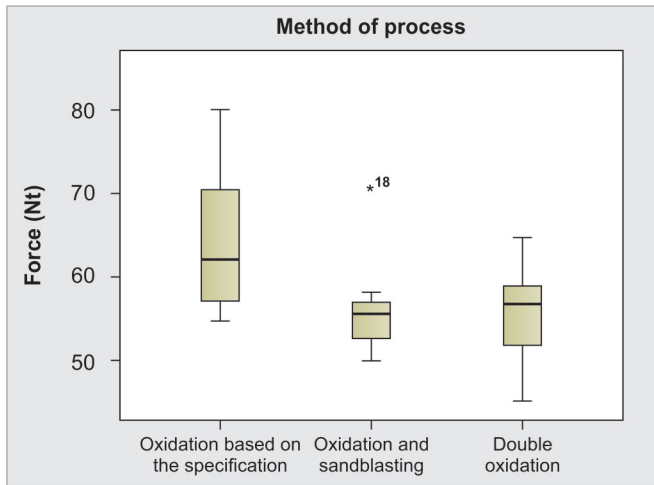


Fig. 2: Overall results of group II (Ni-Cr)

Table 2: Group statistics for groups IA and IB (group I)

	Processing method	N	Mean	Std. deviation	Std. error mean
Force (Nt)	Oxidation and sandblasting	12	64.0283	8.46854	2.44466
	Double oxidation	12	55.9233	5.30201	1.53056

It was concluded that in group I, specification-based oxidation seems to have higher strength rates than oxidation and sandblasting and double oxidation. It is obvious that further treatment of the materials reduces the strength of the materials, especially oxidation and sandblasting, while the effect of double oxidation is lower on the strength of the material.

It is important to notice that despite the differences between the three types of treatment on the strength of the material, the average strength value has significant variations, ranging from 64 Nt (288 MPa) to 54 Nt (216 MPa) approximately, while there is a correlation of the average value in subgroups IIB and IC.

**Results of Optical Microscope for Group Co-Cr Alloy (Group II)**

All specimens from all subgroups exhibited cohesive failure. Inspection of the specimens under the optical microscope showed the persistence, on the fractured metal surfaces, of elements likely to represent elements of opacity and ceramic mass.

**Total Results for Group II (Co-Cr)**

A scoreboard showing the overall results of group II can be found in Figure 2.

Significant differences are observed in group II by distinguishing the results according to the three treatment methods applied to the materials.

The materials with oxidation based on the specifications, show mean value of 58.46.

The oxidation and sandblasting materials have a mean value of 42.56 Nt.

The double oxidation materials have mean 42.96 Nt.

It was noticed that between all three methods there are no significant differences in the mean value but in the range of bending values. Similarly, the specification-based oxidation shows significant differences with the other two processing methods.

The double oxidation method, despite the low range of values it shows, seems to have the highest concentration and despite the limited range, it enables the artisan to have more concentrated

material strength values; also, the double oxidation method shows the lowest material strength values.

Similarly, specification-based oxidation gives a wider range of values which means that it is more difficult for the craftsman to determine more limited range of Nt values that the material can withstand and accordingly advise the customer on the care to be taken in the stresses applied to the material.

It was concluded that in group II, specification-based oxidation seems to have higher strength rates, compared with oxidation and sandblasting and double oxidation. It can be seen that further treatment of the materials reduces the strength of the materials, especially double oxidation, while the effect of oxidation and sandblasting is lower on the strength of the material. Importantly, despite the differences that the three types of treatment show on the strength of the material, the average strength value has significant variations, ranging from approximately 42 Nt (155.4 MPa) to 58 Nt (214.6 MPa), and there is a correlation of the average value in groups IIB and IC.

Certainly, the occurrence of outliers affects the sample averages, but it is clear that specification-based oxidation enhances the strength of the material more than any other method.

**Comparison of the Means of the Two Groups Using the Independent Samples t-Test**

At the same time, the purpose was to compare the means of the two independent groups of measurements at hand, to determine whether the means of the populations from which the samples came are significantly different (independent samples t-test).

**Group I (Ni-Cr Alloy)**

Independent samples t-test criterion was used for groups IA (1-1 to 1-12) and 1B (1-13 to 1-24). The results showed significant differences in resistance values between these groups. Group IA shows mean = 64.02 Nt.

Independent sample t-test criterion was used for groups IB and IC. The results showed non-significant differences in resistance values between these groups. Group IB shows mean = 55.92 Nt. No significant difference is shown as  $t = 0.840 (p) > 0.05$  (Tables 2-5).

Independent samples t-test criterion was used for groups IA and IC. The results showed significant differences in resistance values between these groups. Group IA shows mean = 64.28 Nt. Significant difference is shown as  $t = 0.008 (p) < 0.05$  (Tables 6 and 7).

**Group II (Co-Cr Alloy)**

Independent sample t-test criterion was used for groups IIA (2-1 to 2-12) and 2B (2-13 to 2-24). The results showed statistically non-significant differences in resistance values between these groups. Group IIA shows mean = 58.46 Nt. It shows no statistically significant difference as  $t = 0.180 (p) > 0.05$  (Tables 8-10).

Group independent sample t-test criterion was used for groups IIB (2-13 to 2-24) and 2C (2-25 to 2-36). The results showed statistically non-significant differences in resistance values between these groups. Group IIB shows mean = 42.54 Nt. It shows no significant difference as  $t = 0.968 (p) > 0.05$  (Tables 11).



**Table 3:** Independent samples test for groups IA and IB (group I)

		<i>Levene's test for equality of variances</i>		<i>t-test for equality of means</i>						
		<i>F</i>	<i>Sig.</i>	<i>t</i>	<i>df</i>	<i>Sig. (2-tailed)</i>	<i>Mean difference</i>	<i>Std. error difference</i>	<i>95% Confidence interval of the difference</i>	
									<i>Lower</i>	<i>Upper</i>
Force (Nt)	Equal variances assumed	4.083	0.056	2.810	22	0.010	8.10500	2.88426	2.12341	14.08659
	Equal variances not assumed			2.810	18.475	0.011	8.10500	2.88426	2.05655	14.15345

**Table 4:** Group statistics for groups IB and IC (group I)

	<i>Processing method</i>	<i>N</i>	<i>Mean</i>	<i>Std. deviation</i>	<i>Std. error mean</i>
Force (Nt)	Oxidation and sandblasting	12	55.9233	5.30201	1.53056
	Double oxidation	12	55.4758	5.43613	1.56928

**Table 5:** Independent samples test for groups IB and IC (group I)

		<i>Levene's test for equality of variances</i>		<i>t-test for equality of means</i>						
		<i>F</i>	<i>Sig.</i>	<i>t</i>	<i>df</i>	<i>Sig. (2-tailed)</i>	<i>Mean difference</i>	<i>Std. error difference</i>	<i>95% Confidence interval of the difference</i>	
									<i>Lower</i>	<i>Upper</i>
Force (Nt)	Equal variances assumed	0.569	0.459	0.204	22	0.840	0.44750	2.19208	-4.09861	4.99361
	Equal variances not assumed			0.204	21.986	0.840	0.44750	2.19208	-4.09877	4.99377

**Table 6:** Group statistics for groups IA and IC (group I)

	<i>Processing method</i>	<i>N</i>	<i>Mean</i>	<i>Std. deviation</i>	<i>Std. error mean</i>
Force (Nt)	Oxidation and sandblasting	12	64.0283	8.46854	2.44466
	Double oxidation	12	55.4758	5.43613	1.56928

**Table 7:** Independent samples test groups IA and IC (group I)

		<i>Levene's test for equality of variances</i>		<i>t-test for equality of means</i>						
		<i>F</i>	<i>Sig.</i>	<i>t</i>	<i>df</i>	<i>Sig. (2-tailed)</i>	<i>Mean difference</i>	<i>Std. error difference</i>	<i>95% Confidence interval of the difference</i>	
									<i>Lower</i>	<i>Upper</i>
Force (Nt)	Equal variances assumed	2.444	0.132	2.944	22	0.008	8.55250	2.90499	2.52792	14.57708
	Equal variances not assumed			2.944	18.750	0.008	8.55250	2.90499	2.46678	14.63822

**Table 8:** Group statistics for groups IIA and IIB (group II)

	<i>Processing type</i>	<i>N</i>	<i>Mean</i>	<i>Std. deviation</i>	<i>Std. error mean</i>
Force (Nt)	Oxidation based on the specifications	12	58.4633	33.37539	9.63465
	Oxidation and sandblasting	12	42.5467	21.79189	6.29078

Independent samples *t*-test criterion was used for groups IIA (2-1 to 2-12) and 2C (2-25 to 2-36). The results showed non-significant differences in resistance values between these groups. Group IIA shows mean = 58.46. It shows no significant difference as  $t = 0.231$  ( $p > 0.05$ ) (Tables 12 and 13).

## DISCUSSION

In the present study, the effect of surface treatment of the metal frame on bond strength in metal–ceramic restorations was

investigated. The present study was done using two common categories of alloys for metal–ceramic restorations (Ni–Cr and Co–Cr) and ceramic material (Noritake Ex-3 porcelain), through the three-point bending test method.

In the literature, there are several laboratory tests to check the strength of the metal–ceramic bond. The most used method is the one proposed by the international standardization organization EN ISO 9693 and is the three-point bending method, where the developing stresses can be broken down into shear and tensile ones.<sup>14</sup> The reason why this method is considered more appropriate

**Table 9:** Independent samples test for groups IIA and IIB (group II)

		Levene's test for equality of variances		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% Confidence interval of the difference	
									Lower	Upper
Force (Nt)	Equal variances assumed	3.890	0.061	1.383	22	0.180	15.91667	11.50653	-7.94642	39.77975
	Equal variances not assumed			1.383	18.937	0.183	15.91667	11.50653	-8.17224	40.00557

**Table 10:** Group statistics for groups IIB and IIC (group II)

	Processing method	N	Mean	Std. deviation	Std. error mean
Force (Nt)	Oxidation and sandblasting	12	42.5467	21.79189	6.29078
	Double oxidation	12	42.9683	28.07332	8.10407

**Table 11:** Independent samples test for groups IIB and IIC (group II)

		Levene's test for equality of variances		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% Confidence interval of the difference	
									Lower	Upper
Force (Nt)	Equal variances assumed	0.646	0.430	-0.041	22	0.968	-0.42167	10.25913	-21.69781	20.85447
	Equal variances not assumed			-0.041	20.725	0.968	-0.42167	10.25913	-21.77394	20.93060

**Table 12:** Group statistics for subgroup IIA and IIC (group II)

	Processing method	N	Mean	Std. deviation	Std. error mean
Force (Nt)	Oxidation and sandblasting	12	58,4633	33,37539	9,63465
	Double oxidation	12	42,9683	28,07332	8,10407

**Table 13:** Independent samples test for groups IIA and IIC (group II)

		Levene's test for equality of variances		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% Confidence interval of the difference	
									Lower	Upper
Force (Nt)	Equal variances assumed	1.068	0.313	1.231	22	0.231	15.49500	12.58977	-10.61459	41.60459
	Equal variances not assumed			1.231	21.373	0.232	15.49500	12.58977	-10.65908	41.64908

among laboratory methods is because it is more similar than the others, in terms of the development of stresses on the porcelain–alloy interface. Additionally, the three-point *in vitro* bending test is a clear indication of the metal–ceramic bond strength for the behavior of structures clinically.<sup>7,17,20</sup>

In the three-point bending test, the part of the test piece to which the force (metallic) is applied and compressed, unlike the ceramic coating, is in a tensile state, while the edges of the test piece are in a shear state. From the energy developed in the form of tension through the application of the constant force to the metal surface of the specimen, a part of it is allocated for bending the ceramic material. Another part of it is allocated for the bending of

the metal substrate, and finally a small percentage of the force is lost in the form of frictions.<sup>7,17,20</sup>

On basis of the foregoing, the bending strengths of the ceramic material (breakage) and the metal substrate (deformation) must be greater than the strength of their bonding in order for the system to be evaluated. Second, the binding strength of the two different materials must exceed the minimum acceptable limit of 25 MPa to be successful (EN ISO 9693). This was taken into account and confirmed during the manufacture of metal substrates in this study.

Specifically, for both categories of alloys, the ANOVA test was used to draw conclusions about whether the method of oxidation of the metal substrate (specification-based oxidation





– oxidation and sandblasting – double oxidation) affects the strength of the metal–ceramic bond. Dispersion analysis with one factor showed that in both groups of alloys (Ni–Cr and Co–Cr) the method of oxidation based on specifications has the highest rates of resistance compared with the method of oxidation and sandblasting and the method of double oxidation. In addition, it was found that there is a uniqueness in the range of values, making the test pieces of both groups, regardless of the oxidation method, durable, since the minimum strength values presented were higher than the minimum acceptable limit of 25 MPa of the EN ISO 9693 specification. The mean strength value of the Co–Cr group ranged from 42 Nt to 58 Nt, while that of the Ni–Cr group from 44 Nt to 54 Nt. Owing to this fact, it was deemed necessary to use the independent samples *t*-test, which showed a slight difference in terms of the strength of the metal–ceramic bond in the test pieces of both groups, in favor of the oxidation method based on specifications.

This difference in strength of the metal–ceramic bond recorded during the experimental procedure in favor of the group of specimens that the metal substrate oxidized according to the manufacturer's instructions, may most likely be related to the thickness of the created oxide layer in the alloy and ceramic mesophase.<sup>26–30</sup>

In all metal–ceramic alloys, oxides develop during the oxidation stage, the thickness of the layer of which plays an important role in the strength of the metal–ceramic bond.<sup>16,21,26</sup> The increase in the thickness of the oxide band in the same alloy leads to a decrease in the strength of the metal–ceramic bond, due to reduced transcrystalline actions, from the deformations caused by O<sub>2</sub> in the crystal lattice of oxides. But also, the reduction of the thickness of the oxide band results in the creation of very few retaining molecules and consequently reduced strength of the metal–ceramic bond. It is known that chromium (Cr) creates oxides that do not favor the metal–ceramic bond, and to reduce the negative action its added to alloys containing chromium elements with high chemical affinity for oxygen, such as Hf, Yt, Ti, and Be.<sup>3,5,6,10,15,16,21,26</sup> The average thickness and strength of the oxide belt play a fundamental role in the strength of the metal–ceramic bond. The percentage of oxides is controlled mainly by regulating the temperature and the presence of oxygen (vacuum formation) during the oxidation stage.

Thus, the oxidation of the alloy in strict compliance with the manufacturer's instructions leads to a controlled thickness of the oxide layer, which is what is required for a strong metal–ceramic bond. On the contrary, even a small deviation (increase or decrease) of the oxidation temperature can lead to disturbances of the oxide layer and affect the metal–ceramic bond. An additional parameter that can modify the behavior of the oxide layer is sandblasting, which can often contaminate the surface of the cast, developing disturbances in the alloy–porcelain connection mechanism.<sup>3,5,16,21,26</sup>

Reviewing the literature, it is established that the strength of the metal–ceramic bond with various methods of processing the metal substrate has become the subject of research by many researchers.<sup>30–34</sup>

With regard to the determination of the failure type, the examination of specimens under the optical microscope showed that all test pieces in all three methods used showed cohesive failures. These elements prevailed throughout the surface, since elements of opacity and ceramic mass were observed. This is confirmed by the images obtained from the observation of the specimens with the optical microscope.

The strength of prosthetic restorations is important for their survival in the dynamically changing environment of the human body (temperature change, pH change, chemical changes), especially under the exercise of alternating loads. In particular, the trends that develop in dental restorations during the exercise of chewing loads, are complex. Thus, the selection of the appropriate artificial construction of dental restorations, as well as the appropriate material to be used for their construction, can ensure their protection from breakage.<sup>25–30</sup>

An important limitation of the present study is the fact that only three methods were tested and as such future studies should expand their scope. Additionally, retesting is required to verify these results.

## CONCLUSIONS

The present study concludes that the strength of the metal–ceramic bond of the metal substrates, regardless of the treatment of the metal surface, covers the lower permissible strength limits of the metal–ceramic bond (25 MPa), according to EN ISO 9693, the type of failure for both groups of alloys is cohesive type, which confirms the strength of the bond. Additionally, among the three examined methods of processing the metal surface oxidation shows a superiority in the strength of the metal–ceramic bond (statistically insignificant) based on specifications, due to an increased value of shear strength. In conclusion, it should be stated that to achieve a satisfactory and strong bond in metal–ceramic prosthetic restorations, it is necessary to strictly follow the manufacturer's instructions during the oxidation stage of the alloy.

## REFERENCES

- Abbott SJ. Metal-ceramic restorations. *J Prosthet Dent* 1978 Mar;39(3):293294. DOI: 10.1016/s0022-3913(78)80099-7. PMID: 273091.
- Reitemeier B, Hänsel K, Kastner C, et al. A prospective 10-year study of metal ceramic single crowns and fixed dental prosthesis retainers in private practice settings. *J Prosthet Dent* 2013;109(3):14955. DOI: 10.1016/S0022-3913(13)60034-7. PMID: 23522363.
- Bai R, Sun Q, He Y, et al. Ceramic toughening strategies for biomedical applications. *Front Bioeng Biotechnol* 2022;10:840372. DOI: 10.3389/fbioe.2022.840372.
- Goiato MC, Alves Pesqueira AA, Monteiro DR, et al. Clinical satisfaction and quality of ceramic fixed dentures. *Int J Appl Ceram Technol* 2014, 11:100105. DOI: 10.1111/ijac.12019.
- Fisher H, Dautzenberg G, Marx R. Nondestructive estimation of the strength of dental ceramics materials. *Dent Mater* 2001;17(4):289295. DOI: 10.1016/s0109-5641(00)00086-5.
- Graig RG. *Restorative dental Materials*. The CV Mosby Co: St Louis; 1993.
- Ban S, Anusavice, KJ. Influence of test method on failure stress of brittle dental materials. *J Dent Res*, 1990;69:17911799. DOI: 10.1177/00220345900690120201.
- McLean J. *The science and art of dental ceramics*. Vol. 1. Quintessence: Chicago; 1979.
- McLean J. *Dental ceramics*. Proceedings of the First International Symposium on Ceramics. Quintessence: Chicago; 1983.
- Mehulić K, Laus-Sosić M. Metal-ceramic bond: how to improve? *Minerva Stomatol* 2009;58(78):36773. PMID: 19633637.
- Ashtiani AH, Mardasi N, Fathi A. Effect of multiple firings on the shear bond strength of presintered cobalt-chromium alloy and veneering ceramic. *J Prosthet Dent* 2021;126(6):803.e1803.e6. DOI: 10.1016/j.prosdent.2021.09.021. Epub 2021 Oct 27. PMID: 34716011.
- Yilmaz B, Özçelik TB, Wee AG. Effect of repeated firings on the color of opaque porcelain applied on different dental alloys. *J Prosthet*

- Dent 2009;101(6):395404. DOI: 10.1016/S0022-3913(09)60085-8. PMID: 19463667.
13. Ozcelik TB, Yilmaz B, Ozcan I, et al. Colorimetric analysis of opaque porcelain fired to different base metal alloys used in metal ceramic restorations. *J Prosthet Dent* 2008;99(3):193202. DOI: 10.1016/S0022-3913(08)60043-8.
  14. EN ISO 9693. Metal-ceramic dental restorative systems. 2nd edition. International Organization for Standardization: Geneva, Switzerland; 1999.
  15. Atluri KR, Vallabhaneni TT, Tadi DP, et al. Comparative evaluation of metal-ceramic bond strengths of nickel chromium and cobalt chromium alloys on repeated castings: An in vitro study. *J Int Oral Health* 2014;6(5):99103.
  16. Beck KA, Sarantopoulos DM, Kawashima I, et al. Elemental release from Co-Cr and Ni-Cr alloys containing palladium. *J Prosthet Dent* 2012;21:8893.
  17. Probster, L, Maiwald, U, Weber H. Three point bending strength of ceramics fused to cast titanium. *Eur J Oral Sci* 1996;104:313319. DOI: 10.1111/j.1600-0722.1996.tb00083.x.
  18. Ghiban A, Moldovan P. Study of corrosion behavior under simulated physiological conditions of dental Co-Cr-Mo-Ti alloys. *U.P.B. Sci Bull* 2012;74:203214.
  19. Vásquez VZ, Ozcan M, Kimpara ET. Evaluation of interface characterization and adhesion of glass ceramics to commercially pure titanium and gold alloy after thermal- and mechanical-loading. *Dent Mater* 2009;25(2):221231. DOI: 10.1016/j.dental.2008.07.002. Epub 2008 Aug 20.
  20. Ohno H, Kanzawa Y. Structural changes in the oxidation zones of gold alloys for porcelain bonding containing small amounts of Fe and Sn. *J Dent Res* 1985;64(1):6773. DOI: 10.1177/00220345850640011401.
  21. Shillingburg HT, Hobo S, Fisher DW. Preparation design and margin distortion in porcelain fused to metal restorations. *J Prosthet Dent* 1973;29(3):276. DOI: 10.1016/0022-3913(73)90007-3.
  22. Brodbelt RHW, O'Brien WJ, Fan RL. Translucency of dental porcelains. *J Dental Res* 1980;59(1):7075. DOI: 10.1177/00220345800590011101.
  23. Asgar K, Arfaei AH. Castability of crown and bridge alloys. *J Prosthet Dent* 1985;54(1):6063. DOI: 10.1016/s0022-3913(85)80071-8.
  24. Lee SK, Wilson PR. Fracture of all-ceramic crowns with varying core elastic moduli. *Aust Dent J* 2000;45(2):103107.
  25. Kerber SJ. The complementary nature of X ray photoelectron spectroscopy and angle resolved X ray diffraction. II. Analysis of oxides on dental alloys. *J Material Engl Perform* 1998;7:334342.
  26. Cramber DA, Goldstein RE. Cast - ceramic systems and other alternatives in porcelain and composite inlays and outlays - Esthetic posterior restorations. Quintessence Books: Michigan; 1994.
  27. Schweizer DM, Goldstein GR, Ricci JL, et al. Comparison of bond strength of a pressed ceramic fused to metal versus feldspathic porcelain fused to metal. *J Posthodont* 2009;14(4):239247. DOI: 10.1111/j.1532-849X.2005.00052.x.
  28. Akagi M, Okamoto Y, Matsura T, et al. Properties of test metal ceramic titanium alloys. *J Prosthet Dent* 1992;68:462467. DOI: 10.1016/0022-3913(92)90411-3.
  29. Rathi S, Parkash H, Chittaranjan B, et al. Oxidation heat treatment affecting metal-ceramic bonding. *Indian J Dent Res* 2011;22(6):877878. DOI: 10.4103/0970-9290.94664.
  30. Li J, Ye X, Li B, et al. Effect of oxidation heat treatment on the bond strength between a ceramic and cast and milled cobalt-chromium alloys. *Eur J Oral Sci* 2015;123(4):297304. DOI: 10.1111/eos.12199.
  31. Patel KA, Mathur S, Upadhyay S. A comparative evaluation of bond strength of feldspathic porcelain to nickel-chromium alloy, when subjected to various surface treatments: An in vitro study. *J Indian Prosthodont Soc* 2015;15(1):5357. DOI: 10.4103/0972-4052.155036.
  32. Lahori M, Nagrath R, Sisodia S. The effect of surface treatments on the bond strength of a nonprecious alloy-ceramic interface: An in vitro study. *J Indian Prosthodont Soc* 2014;14(2):151-155. DOI: 10.1007/s13191-013-0285-3.
  33. Vojdani M, Shaghaghian S, Khaledi A, et al. The effect of thermal and mechanical cycling on bond strength of a ceramic to nickel - chromium (Ni-Cr) and cobalt-chromium (Co-Cr) alloys. *Indian J Dent Res* 2012;23(4):509513. DOI: 10.4103/0970-9290.104960.