

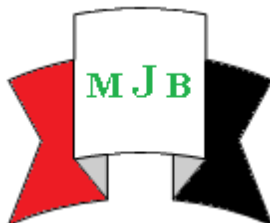
The Effect of Metal Surface Treatment before Reporcelainization for Ceramic Repair After Adhesive Fracture of Ceramo-Metallic Restoration

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Abstract

The high cost of the precious metals has simulated interest in less expensive alloys for the casting of Crown & Bridge. Several non precious metal alloys based on Nickel and/or Cobalt Chromium alloys have become commercially available for the use with fusing porcelain (ceramic).

The purpose of the present work was two folds:

1- To investigate the effect of different metal surface treatment (sandblasting, grinding and grinding followed by sandblasting) before reporcelainization (reapplication of porcelain after adhesive fracture) of the bare metal on the bond strength.

2- To give some light on the mechanism of metal ceramic bonding through the use of metallographic microscopic study.

Two non-precious dental casting alloys Nickel- Chromium and Cobalt- Chromium alloys and one type of dental ceramic were used in this study. The conclusions from the study weresandblasting increases the bond strength of metal/ceramic interface for both the investigated alloys, and the Cobalt- Chromium alloy showed better bond strength with sandblasting than the Nickel- Chromium.

الخلاصة

ارتفاع تكلفة المعادن الثمينة يتطلب ايجاد سبائك أقل تكلفة لعمل التاج وجسور الاسنان . أصبحت العديد من سبائك المعادن الغير الثمينة من النيكل أو سبائك الكوبالت الكروم متاحة تجاريا للاستخدام ويتم خلطها مع الخزف (السيراميك). كان الغرض من هذا العمل لسببين:

- ١- لتحقيق تأثير مختلف في معالجة أسطح المعادن (الصب الرملي، والسقل والسقل ثم الصب) قبل إعادة التخزيف (استخدام الخزف بعد كسر اللاصق) للمعدن المكشوف على قوة الارتباط. ٢- وإعطاء بعض الضوء على آلية ترابط المعدن مع السيراميك من خلال دراسة وفحص المعادن باستخدام المجهر. وتم استخدام اثنين من سبائك الأسنان غير الثمينة وهي النيكل - الكروم وسبائك الكروم-كوبالت ونوع واحد من سيراميك الأسنان في هذه الدراسة. الاستنتاجات من هذه الدراسة هو ان الصب الرملي يزيد من قوة الارتباط للمعادن/سطح السيراميك لكل من سبائك البحث وسبائك الكروم- كوبالت، وأظهرت أفضل قوة ارتباط مع الصب الرملي من النيكل - الكروم.

Introduction

Ceramic fracture over non-precious crown coping is a common clinical problem. It occurs always during cementation procedure or short after cementation and causes a great problem for the clinician. Repair of fractured ceramic takes place if the fracture happens during check up for cementation, the clinician immediately sends to the lab for correction

which is done by different approach. Reapplication of the ceramic on the fractured area and firing it again (reporcelainization). The lab may sandblast the bare area before reapplication of ceramic or not, exposing the restoration to the effect of multiple firings. This problem is of great importance since till now there is lack of literature/researches that investigate this point, especially the relationship between reapplication of ceramic on the metal surface after ceramic failure and

the new bond strength between the reapplied ceramic and metal. This study is intended to share in solving the problem in regard to the best treatment of bare metal for the best bond strength.

The porcelain fused to metal (PFM) system has been used in dentistry for close to 50 years.

From the compositional point of view many alloys are developed, the most commonly used are two classes, namely Nickel base and Cobalt base alloys, these alloys are basis for superior ceramo-metallic restorations.

Dental ceramic has two disadvantages of being brittle (can fracture from trauma or mastication) and difficult to repair.

Ceramic fracture is a serious and costly problem for the patient and dentist. The increase use of ceramic restorations engenders the need for reliable ceramic repair system.

Most of studies were done on cohesive and not adhesive fracture of ceramic.

Clinically adhesive fracture is treated by remake the restoration or by reporcelanization of the fracture ceramic at the dental laboratory.

On the other hand only limited researches were concerned about reporcelainization, because till now there is no exact solution for this problem. This study is intended to share in solving the problem in regard to the best treatment of bare metal for the best bond strength.

Materials and Methods

Two non-precious dental casting alloys, a nickel-chromium alloy, Wiron 88 dental casting alloy*, and a cobalt-chromium alloy, Remanium 2000 dental casting alloy**, and one type of dental ceramic, Vita VMK 68 dental ceramic*** were used in this study.

A total of 80 rod shaped metallic samples (35mm. Long and 2.4mm. in diameter), 40 samples for each alloy, were used for bond strength measurements and for metallographic study.

*Bergo Bremer Gold Scglageri with Herbst GmbH & Co., West Germany

** Post Fach 440, D-7530 Pfozheim, Fed. Rep. of Germany.

***Vita Zahnhmfabrik, H. Rauter GmbH & Co., West Germany

Preparation of the specimens:

Thirty five millimeter length from plastic sprue formers of 2.4 mm in diameter were cut off representing the plastic patterns of the rod shaped samples

All the patterns were oriented over crucible formers. Stainless steel casting rings lined with asbestos liner were applied over, and invested with phosphate bonded investment*. Burning out was done and casting was carried out using induction casting machine**. After casting, the casting rings were left to cool (Fig.1) and the rods were removed from the rings then were cut off and finally the rods were sandblasted with 250 micron aluminum oxide and porcelained with one type of ceramic. Then specimens became ready for ceramic core application (Fig.2).

Fig. (1): Photograph of the cast rods oriented over crucible former after casting.

Fig. (2): Photograph of the finished samples ready for ceramic core application.

Porcelainization of the samples:

The design of porcelainized rods used for testing the bond strength was based on the third design described by Shell and Nielsen⁽¹⁾.

This was done by applying rubber support (5 mm. long) around the rod leaving 8-10 mm. length bared from the upper end of the rod. Two thin plastic components (thin perforated plastic base and thin wall plastic tube) were used to form a temporary mold (6mm. long) for the ceramic Vita VMK 68 was mixed and condensed around the rods according to the manufacturer's instructions. Samples were then ready for measuring the shear bond strength. All bond strength measurements were done in one day for each alloy i.e. the same condition of temperature and environments. The fracture of all the samples was adhesive type between ceramic and metal.

After removal of ceramic traces, three different methods of surface treatment of the bare metal were done for each alloy-ceramic system beside a group of no surface treatment.

This was classified into four groups as follows:

- 1- No treatment was done for bare metal after fracture (direct application of ceramic on bare metal).
- 2- Grinding of bare metal before reapplication of ceramic was done using rotary drilling machine. This group was divided into two groups, which were roughened at two different grades of emery paper (P120D and P600C)
- 3- Grinding followed by sandblasting of bare metal was done before reapplication of ceramic on bare metal. This group was divided into two groups, which were roughened (ground) with two different grades of emery paper (P120D and P600C). Sandblasting was done with 250 micron aluminum oxide (Al_2O_3).
- 4- Sandblasting with 250 micron aluminum oxide of bare metal was done before reapplication of ceramic on bare metal.

*Hi- Temp whip mix Corporation, 361 Farming Ave., Louisville, Kentucky, U.S.A.

**Buffalo Dental MFG. Company, Inc. 575, underhill Blvd, U.S.A.

Each of the four groups contains 10 rods (8 rods for bond strength measurement and 2 rods for metallographic study)

All samples were then porcelainized again in the same way described before and were tested for shear bond strength. The results of the mechanical testing were tabulated and statistically analyzed. Metallographic microscopic examination of the interface was done for all the samples.

Technique of grinding the metal samples:

The rod specimens were roughened using silicon carbide grinding paper (according to the grouping of the samples). Grade P120D for the most rough surface, and P600C for the smoother surface roughened were used in this study.

The rods were roughened by fixing them in a rotary drilling machine while the specific grade of silicon carbide grinding paper was applied over the rotating rod in a horizontal position.

Roughening of the specimens with P120D grade was done gradually, starting from grade 60, then 80, and finally with P120D, while with P600C was also done gradually, starting from grade P120D, then P150C, then P180C, then P320C, then P400C and finally with P600C (the surfaces were cleaned ultrasonically then with alcohol).

Methods of testing:

1) Testing of bond strength:-

Bond strength was measured using a universal testing machine*.

A specially designed tool device 10x10 cm. and 10 cm. height (fig.3) was adapted to the universal testing machine (fig.4) for emphasizing the shear bond strength. This was done by holding the upright rod of the specially designed device in the upper holder compartment of the testing machine, while the lower holder compartment was holding the lower part of the testing machine, while the lower holder compartment was holding the lower part of the testing rod which had been passing freely through the central hole of the base of the device (fig.5).

Fig. (3): Photograph of the specially designed steel device.

Fig. (4): Photograph of the steel device in position in the universal testing machine.

Fig.(5): Photograph of the steel device attached to the universal testing machine and holding the test sample.

1) Metallographic study:

For metallographic study, the rod shaped samples were embedded vertically in a thermoplastic resin to facilitate polishing, etching and examination. After resin hardening, specimens were flattened by grinding under a jet of water, using rotating grinding machine with different grades of silicon carbide emery papers from grade P120D to P600C used to expose upper end of the samples at which the metal-ceramic interface present.

*VEBWERKSTOFFPRUKUFMachine,
LEIPZIG,Fabr.Nr.279h7, Germany.

A mirror like surface was achieved through the use of rotating wheel, covered with a special cloth, charged with alumina (fib.6). the polished surface was etched using the following solutions:-

1) Nitric acid 30% Conc.

2) Hydrochloric acid 70% Conc.

The immersion time ranged from 2-6 minutes

- Metallographic examination was carried out using one type of metallographical microscope*.

- Fig. (6) Photograph of the pocelainized rods embedded in a thermoplastic resin and polished.

Results

1- Bond strength evaluation test:

The shear bond strength of ceramo-metal interface were investigated and computed. The results of the mean values of the bond strength test of both alloys before metal surface treatment (before reporcelainization) are shown in the (Table 1).

Table 1: mean values of the shear bond strength test before reporcelainization_Bond strength. Mean kg/cm²

Alloys	No.	Mean	S.D.	Mean $\pm \Delta X$
Ni-Cr	32	296	62	296 $\pm$ 14
Co-Cr	32	333	48.15	333 $\pm$ 11

*Inverted specimen metallographic microscope. Carizeiss,Jena,Germany.

S.D. = Standard deviation
 $\pm \Delta X$ = Standard error at confidence of 95%.

From the table (1) it is shown that the Co-Cr alloy exhibited the highest mean bonding value followed by Ni-Cr.

1-1- Effect of surface treatment on bond strength:-

The results of the mean values of the bond strength test of both alloys after metal surface treatment (after reporcelainization) are shown in the table (2).

Table 2: Effect of metal surface treatment on shear bond strength. Bond strength. Mean Kg/cm²

B.S.= Bond strength

S.D.= Standard deviation

Condition	Ni-Cr				Co-Cr			
	No.	B. S.	S. D.	Mean $\pm \Delta X$	No.	B. S.	S.D.	Mean $\pm \Delta X$
No treatment	8	290	24	290 $\pm$ 14	8	330	25	330 $\pm$ 15
Grinding P120D	4	282.5	18	282.5 $\pm$ 16	4	326	30	326 $\pm$ 26
Grinding P600C	4	284	34	284 $\pm$ 29	4	330	22.6	330 $\pm$ 19.6
Grind.P600+sand-blasting	4	341	20	341 $\pm$ 8	4	354.2	17	354.2 $\pm$ 15
Grind.P120+sand-blasting	4	314.5	47	314.5 $\pm$ 10	4	370	24	370 $\pm$ 21
Sandblasting	8	356.2	30	356.2 $\pm$ 17	8	370	30.1	370 $\pm$ 17.2

$\pm \Delta X$ = Standard error at confidence of 95%.

1-2- Effect of surface treatment on Ni-Cr alloy:

From table (2), it is shown that in case of Ni-Cr alloy the highest mean bond strength was obtained when the bare metal was treated with sandblasting and had the mean of 356.3 Kg/cm², then grinding with P600C silicon carbide emery paper followed by sandblasting and had the mean of 341 kg/cm², then grinding with P120D silicon carbide emery paper followed by sandblasting and had the

mean of 314.5 kg/cm², then direct application of ceramic on bare metal and had the mean of 290 kg/cm², then grinding with P600C silicon carbide emery paper and had the mean of 284kg/cm², then the lowest bond strength was obtained with grinding with P120D silicon carbide emery paper and had the mean of 282.5kg/cm².

Figure-7 shows mean bond strength of Ni-Cr alloy after metal surface treatment.

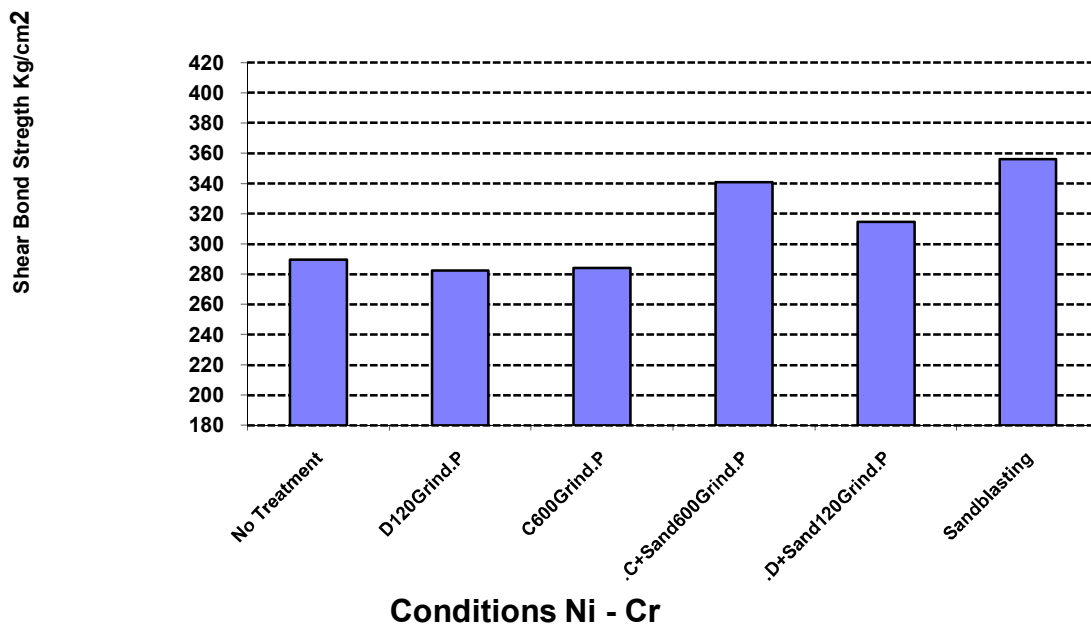


Figure 7: Histogram showing the mean shear bond strength of Ni-Cr alloy at different metal surface treatment

1-3- Effect of surface treatment on Co-Cr alloy

From table (2), it is shown that in case of Co-Cr alloy, the highest mean bond strength was obtained when the bare metal was treated with sandblasting and when it was treated with grinding with P120D silicon carbide emery paper followed by sandblasting and had the same mean of 370kg/cm², then P600C silicon carbide emery paper followed

by sandblasting and had the mean of 354.2 kg/cm², then both groups grinding with P600C silicon carbide emery paper and the group of no surface treatment (direct application of ceramic on bare metal) had the same mean of 330kg/cm², the lowest mean bond strength was obtained with P120D silicon carbide emery paper and had the mean of 326kg/cm².

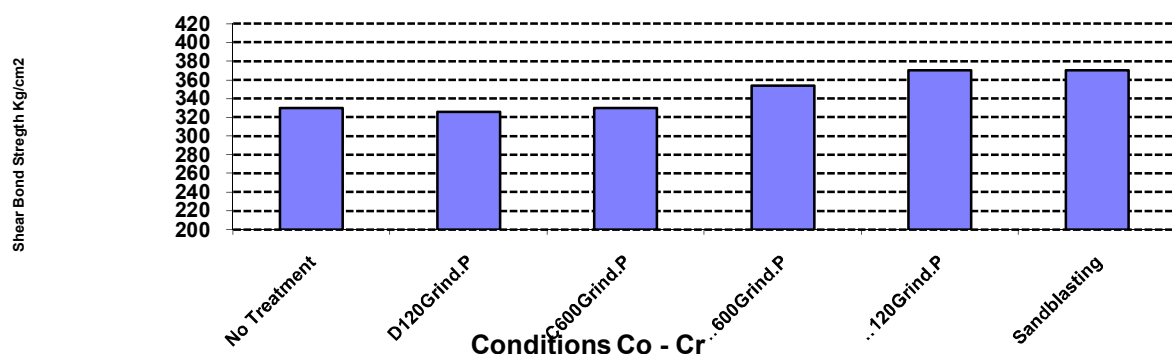


Figure 8: shows mean shear bond strength of Co-Cr alloy after metal surface treatment.

(Figure 8): histogram showing the mean shear bond strength of Co-Cr alloy at different metal surface treatment.

Also, from the above table, if we compare the mean bond strength of two alloys together, we find that, the highest mean bond strength was obtained from Co-Cr alloy when the bare metal was treated with sandblasting and when it was treated with grinding P120D silicon carbide emery paper followed by

sandblasting, and had the same mean of 370kg/cm². The lowest mean bond strength was obtained from the Ni-Cr alloy when the bare metal was treated by grinding with P120D silicon carbide emery paper, and had the mean bond strength of 282.5kg/cm².

The results of the mean value of bond strength test of both alloys after metal surface treatment (after reporcelainization) are shown in the table (3).

Table 3: Mean values of the shear bond strength test after reporcelainization.

Bond strength.Mean kg/cm²

Alloys	No.	Mean	S.D.	Mean $\pm \Delta X$
Ni-Cr	32	314.3	31	314.3 $\pm$ 7
Co-Cr	32	347.5	26	347.5 $\pm$ 6

S.D. = Standard deviation

$\pm \Delta X$ = Standard error at confidence of 95%

From the above table, it is shown that the Co-Cr alloy exhibited the highest mean bonding value followed by Ni-Cr alloy.

2-1-The metallography of Ni-Cr alloy:

The structure features of the Ni-Cr alloy investigated are characterized by a matrix (white phase) which is mainly Ni-Cr solid solution, and a dark islands which are mainly tertiary and quaternary eutectics of the minor elements compounds with the base elements nickel and/chromium. Photomicrograph (9) shows that these islands may appear as spots or lines according to the section orientation of the grain boundaries.

Fig. (9): Photomicrograph of the Ni-Cr alloy.(Magnification 200x4).

2-2-Ni-Cr alloy/ceramic:

The alloy ceramic interface has been investigated to show the role of surface treatment on the interaction zone at the interface.

2-2-1-Ni-Cr alloy/ceramic system before metal surface treatment:

Fig. (10) Photomicrograph shows a straight interface and reaction zones that incorporated to bond strength.

Fig. (10) Photomicrograph of Ni-Cr alloy/ceramic interface before metal surface treatment. (Magnification 200x4).

2-2-2-Ni-Cr alloy/ceramic system without metal surface treatment:

Fig. (11) Photomicrograph of the alloy/ceramic interface shows that the main structural features of the interface are the same as the previous groups (porcelainized sample).

Fig.(11): Photomicrograph of the Ni-Cr alloy/ceramic interface without metal surface treatment (Magnification 200x4).

2-2-3-Ni-Cr alloy/ceramic system with rough grinding (P120D):

Fig.(12) Photomicrograph shows that cross sectional areas of contact are more or less straight. Reaction zones are produced at the nodes of cell boundaries.

Fig. (12): Photomicrograph of the Ni-Cr alloy/ceramic interface with rough grinding (P120D). (Magnification 200x4).

2-2-4-Ni-Cr alloy/ceramic system with fine grinding (P600C):

The same structural features were obtained as shown in Photomicrograph (13).

Fig. (13): Photomicrograph of the Ni-Cr alloy/ceramic interface with fine grinding (P600C). (Magnification 200x4).

2-2-5-Ni-Cr alloy/ceramic system with grinding followed by sandblasting:

The structure features of these groups show clearly that these groups are the same as the group of sandblasting Photomicrograph Fig. (14, 15).

Fig. (14): Photomicrograph of the Ni-Cr alloy/ceramic interface with rough grinding (P120D) followed by sandblasting. (Magnification 200x4).

Fig. (15): Photomicrograph of the Ni-Cr alloy/ceramic interface with fine grinding (P600C) followed by sandblasting of bare metal surface.(Magnification 200x4).

2-2-6-Ni-Cr alloy/ceramic system with sandblasting of bare metal surface:

Fig.(16) Photomicrograph shows that the reaction zone is clearly shown indicating the existence of the oxidation/reduction reactions. Intense reaction areas are shown as a result of interaction of cell boundaries and the ceramic.

Fig. (16): Photomicrograph of the Ni-Cr alloy/ceramic interface with sandblasting of bare metal surface.(Magnification 200x4).

2-3-The metallography of Co-Cr alloy:

The structure features of the Co-Cr alloy are composed of Co-Cr solid solution forming the matrices and surrounded by tertiary and quaternary eutectics forming the cell boundaries. The metallographic picture of Co-Cr alloy is shown in Photomicrograph Fig. (7).

Fig. (17): Photomicrograph of the Co-Cr alloy.(Magnification 200x4).

2-4-Co-Cr alloy/ceramic:

The alloy ceramic interfaces have been investigated to show the role of surface treatment on the interaction zone at the interface.

2-4-1-Co-Cr alloy/ceramic system before metal surface treatment:

Fig.(18) Photomicrograph shows a straight interface and reaction zones that incorporated to bond strength.

Fig.(18) Photomicrograph of Co-Cr alloy/ceramic interface before metal surface treatment. (Magnification 200x4).

2-4-2-Co-Cr alloy/ceramic system without metal surface treatment:

The main structural features of the interface are the irregularities of the interface.

Fig.(19) Photomicrograph shows the interface.

Fig. (19): Photomicrograph of the Ni-Cr alloy/ceramic interface without metal surface treatment (Magnification 200x4).

2-4-3-Cobalt-Chromium alloy/ceramic system after rough grinding (P120D):

Fig.(20) Photomicrograph shows the alloy/ceramic interface. It is clearly shown that the interface is more or less straight indicating less reaction areas are present between the alloys and ceramic.

Fig. (20): Photomicrograph of the Co-Cr alloy/ceramic interface with rough grinding (P120D).(Magnification 200x4).

2-4-4- Cobalt-Chromium alloy/ceramic system after fine grinding (P600C):

Fig.(21) Photomicrograph shows the alloy/ceramic interface which is more or less straight indicating less reaction are present between alloy and ceramic.

Fig. (21): Photomicrograph of the Co-Cr alloy/ceramic interface with fine grinding (P600C).(Magnification 200x4).

2-4-5-Cobalt-Chromium alloy/ceramic system after grinding followed by sandblasting:

Fig.(22, 23) Photomicrographs show the structural features of these groups resembling the group sandblasting.

Fig. (22): Photomicrograph of Co-Cr alloy/ceramic interface after rough grinding (P120D) followed by sandblasting. (Magnification 200 x 4)

Fig. (23): Photomicrograph of Co-Cr alloy/ceramic interface with fine grinding (P600C) followed by sandblasting. (Magnification 200 x 4)

2-4-6- Cobalt-Chromium alloy/ceramic system after sandblasting of bare metal surface:-

Fig.(24) Photomicrograph shows the interface. Reaction zone is clearly shown indicating the existing of the oxidation/reduction reactions as a result of interaction of cell boundaries and the porcelain. The interface produced an irregular surface.

Fig. (24): Photomicrograph of Co-Cr alloy/ceramic interface with sandblasting of bare metal surface. (Magnification 200 x 4).

Discussion

Porcelain fracture over non-precious crown copings is a common clinical disaster. It occurs always during cementation procedure or shortly after cementation and cause a great problem for the clinicians. This problem is of great importance since till now there is lack of literature that investigates this point, specifically the relationship between reapplication of porcelain on bare metal surface and the new bond strength between the reapplied porcelain and metal⁽²⁾.

The first group shows that, there is slight reduction in the mean bond strength after direct application of porcelain on bare metal; this reduction is of no statistical significant difference.

There is also no statistical significant difference in the reduction in the mean shear bond strength in the second group in which the bare metal surface after fracture was ground with different grades of emery paper. There is an increase in the mean shear bond strength in the third group in which the bare metal was ground with different grades of emery paper followed by sandblasting. This increase in the bond strength is also of no statistical significant difference.

The results in the fourth group in which the bare metal was sandblasted only, show an increase in the mean shear bond strength. This increase is of statistical significance.

Sandblasting as a surface treatment has a contradictory effect on the bond strength⁽²⁻⁸⁾. Some authors believe that sandblasting increases the shear bond strength^(2, 3, 4, 7, and 9).

Others believe that it has no effect.

Some authors^(8, 11, and 12) said that, the contribution of surface roughness by air abrasion has been attributed to enhancement of proper wetting of the alloy by the porcelain. Proper wetting also provides additional mechanical interlocking and increases the surface area for the porcelain attachment.

Sutow E et al⁽¹³⁾ found that bond strength is not necessarily a function of the final abrasives selected for mechanical surface finishing.

Shehata MT *et al*⁽²⁾, said in their study that, according to the assumption that says "during firing of porcelain on the base metal alloy, it always consume the active bonding elements present at the metal side of the interface"^(6, 14, 15), sandblasting the metal before reporcelainization should create a new metal surface containing fresh bonding elements and form a higher bond strength. But their result was in the contrary of the results of this study, sandblasting the metal surface before reporcelainization caused insignificantly weaker bond strength. They said that this may be due to the thickness of the metal which was removed during sandblasting was not enough to create a new surface that contain enough bonding elements capable to increase the bond strength.

Sandblasting induces a thin strained or deformed layer^(16, 17). The thickness of the deformed layer depends on the duration, energy of the blasted particles and the ductility of the alloy.

Two mechanisms may influence the deformed thin layer during porcelainization.

(1) Recovery i.e. the strained layer evolves energy that may activate the oxidation/reduction reactions at the interface.
 (2) Recrystallization i.e. Grain refinement is taken place during porcelainization, that may increase the irregularities at the metal/porcelain interface. More work is needed to clarify the effect of sandblasting on the porcelainization process. The response of alloys to the process of recovery and recrystallization is inherent property of the alloy. This may explain the variation of the response to sandblasting of different dental alloys to the porcelainization process.

This may explain the lowering in bond strength in the ground specimen i.e. the deformed layer has been removed by grinding and no strained layer at the interfaces.

Conclusion

- (1) It is possible to repair the metal/porcelain restoration interface after adhesive fracture that occurs mainly during try in and cementation procedures.
- (2) Direct reporcelainization (without metal surface treatment) on the bare metal also gives adequate bond strength.
- (3) Sandblasting increases the bond strength of metal/porcelain interface for both the investigated alloys, namely Ni-Cr and Co-Cr.
- (4) The cobalt-chromium alloy shows better bond strength with sandblasting than the nickel-chromium alloy.
- (5) Grinding procedure should not be used as a metal surface treatment before reporcelainization because it lowers the bond strength in case of base metal alloys.

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Figure 1: Photograph of the cast rods oriented over crucible former after casting.

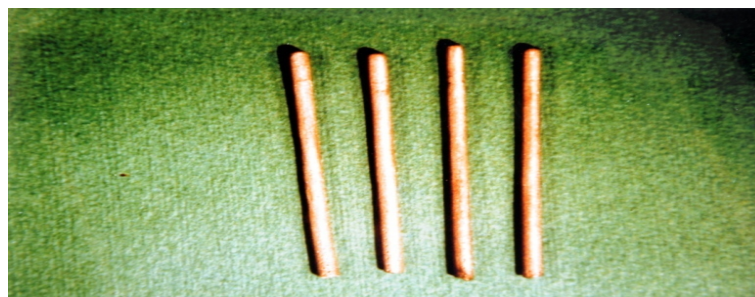


Figure 2: Photograph of the finished samples ready for ceramic core application.

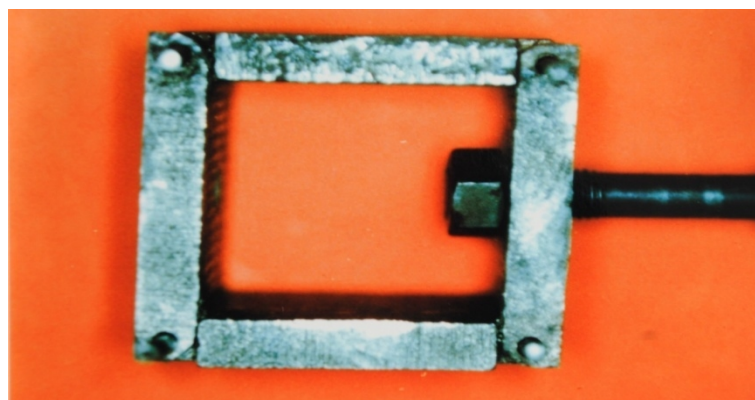


Figure 3: Photograph of the specially designed steel device.

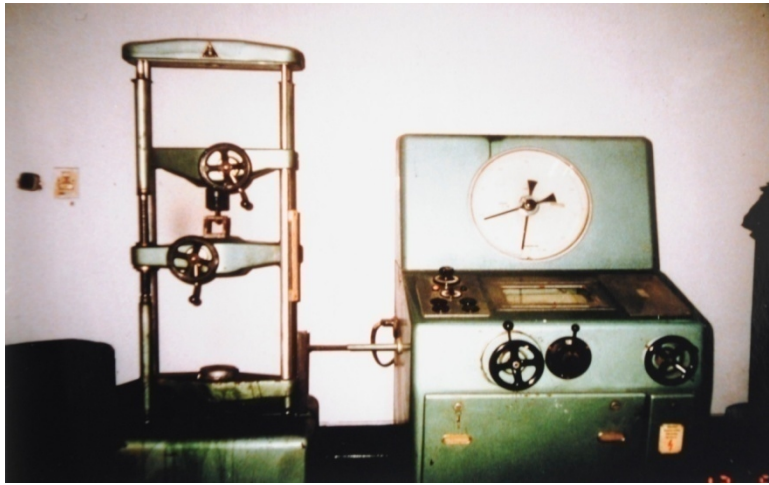


Figure 4: Photograph of the steel device in position in the universal testing machine.

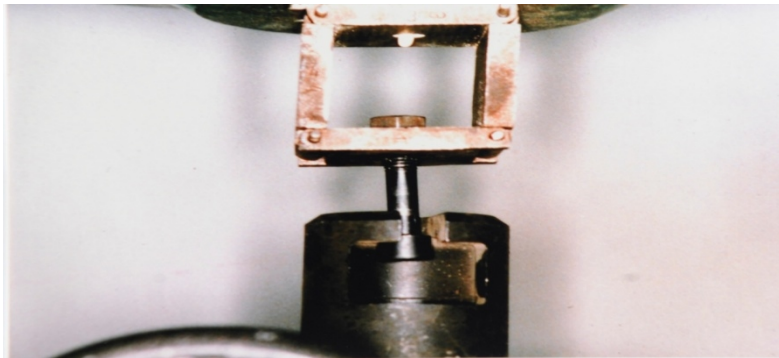


Figure. 5: Photograph of the steel device attached to the universal testing machine and holding the test sample.

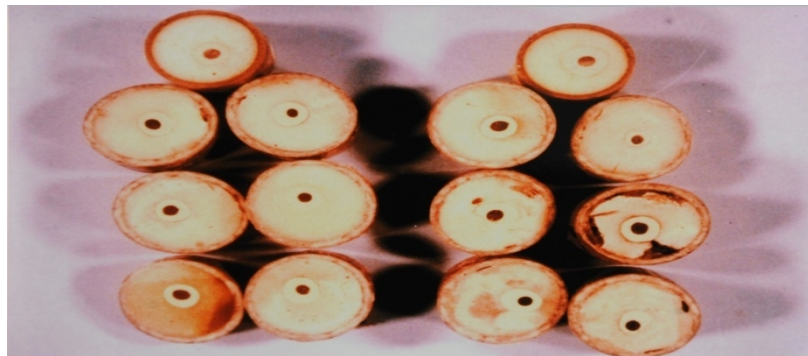


Figure 6: Photograph of the pocelainized rods embedded in a thermoplastic resin and polished.

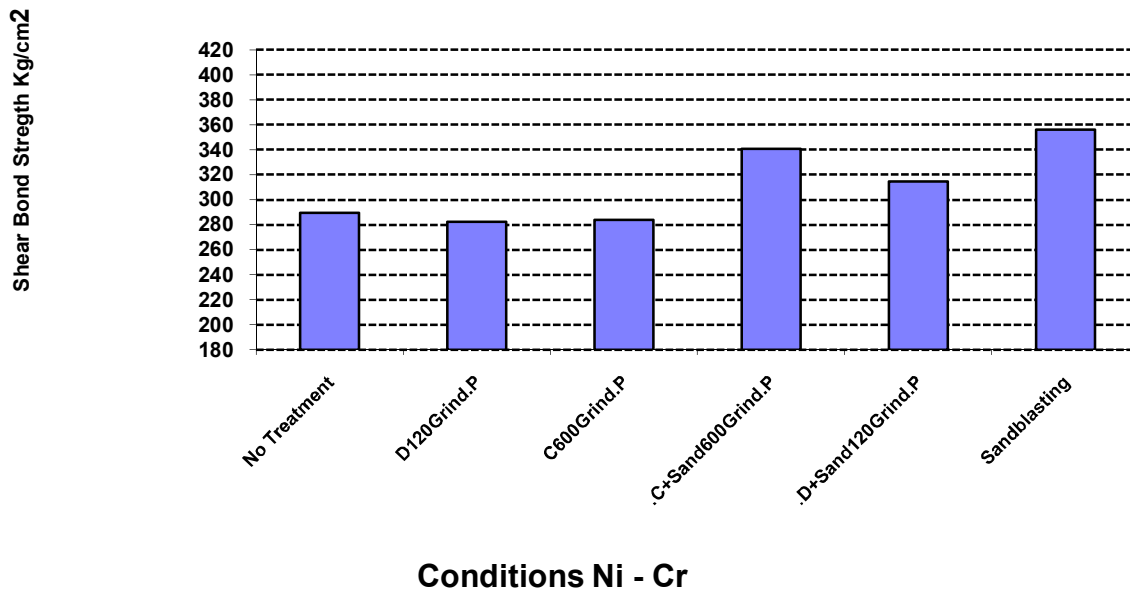


Figure 7: Histogram showing the mean shear bond strength of Ni-Cr alloy at different metal surface treatment.

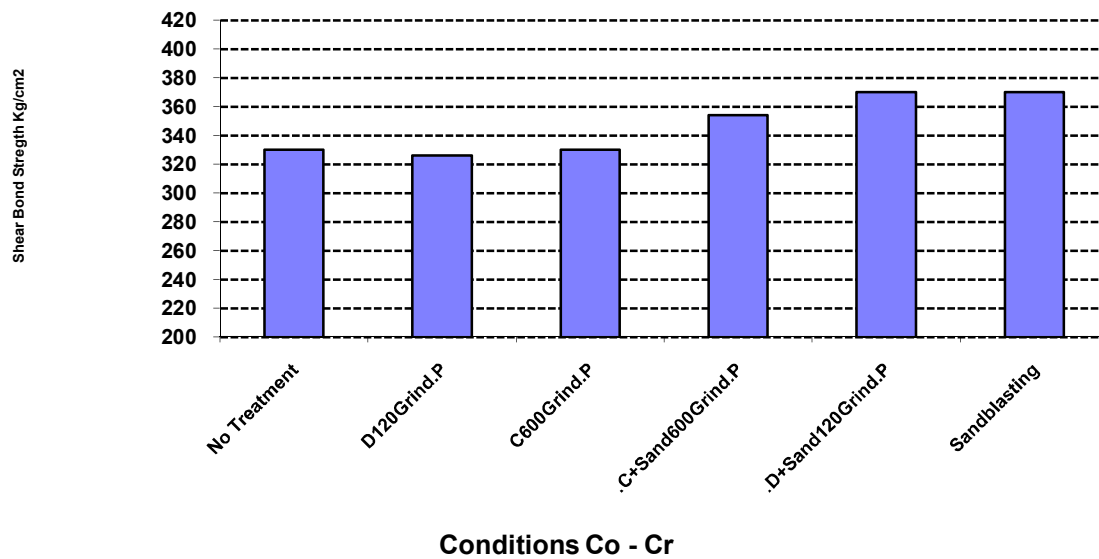


Figure 8: Histogram showing the mean shear bond strength of Co-Cr alloy at different metal surface treatment.

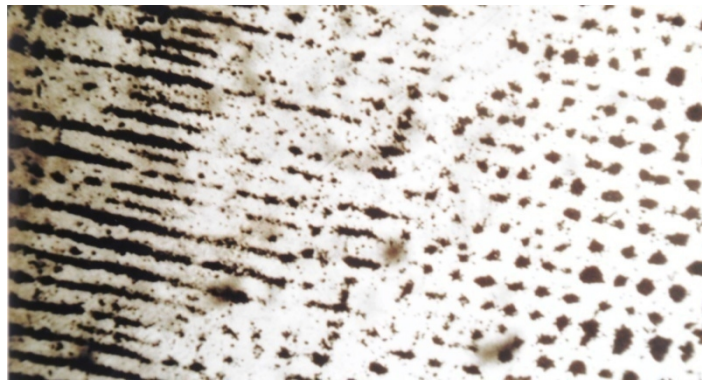


Figure 9: Photomicrograph of the Ni-Cr alloy.(Magnification 200x4).

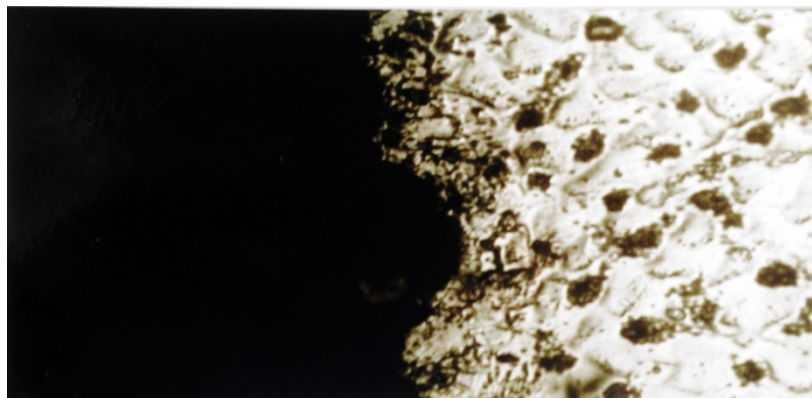


Figure 10: Photomicrograph of Ni-Cr alloy/ceramic interface before metal surface treatment. (Magnification 200x4).

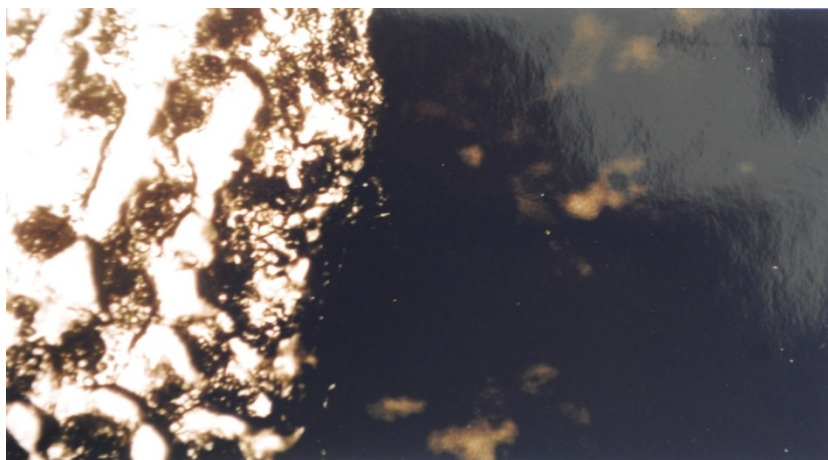


Figure 11: Photomicrograph of the Ni-Cr alloy/ceramic interface without metal surface treatment (Magnification 200x4).

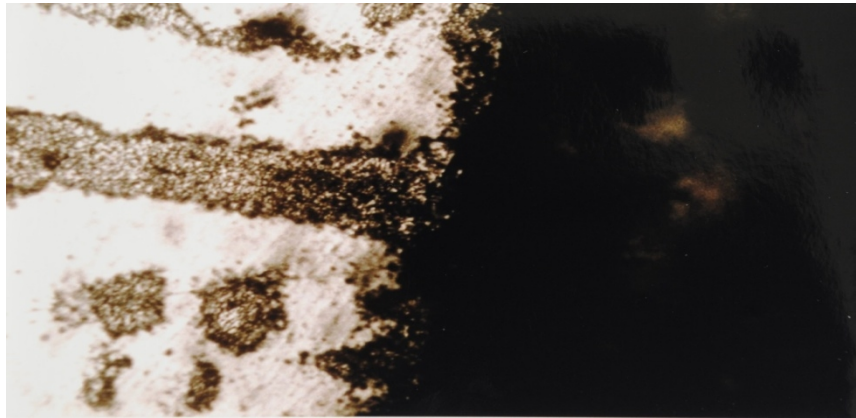


Figure 12: Photomicrograph of the Ni-Cr alloy/ceramic interface with rough grinding (P120D).(Magnification 200x4).

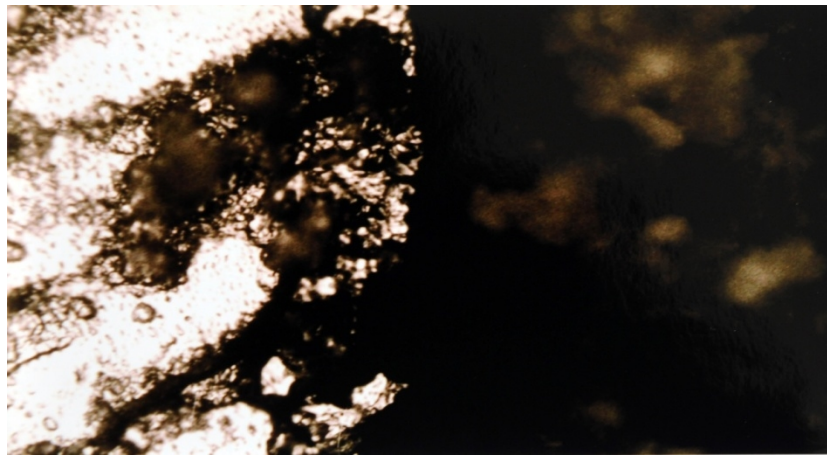


Figure 13: Photomicrograph of the Ni-Cr alloy/ceramic interface with fine grinding (P600C).(Magnification 200x4).

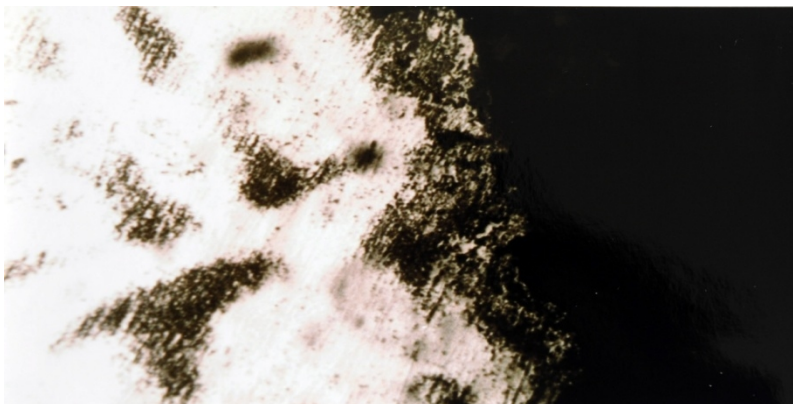


Figure 14: Photomicrograph of the Ni-Cr alloy/ceramic interface with rough grinding (P120D) followed by sandblasting.(Magnification 200x4).

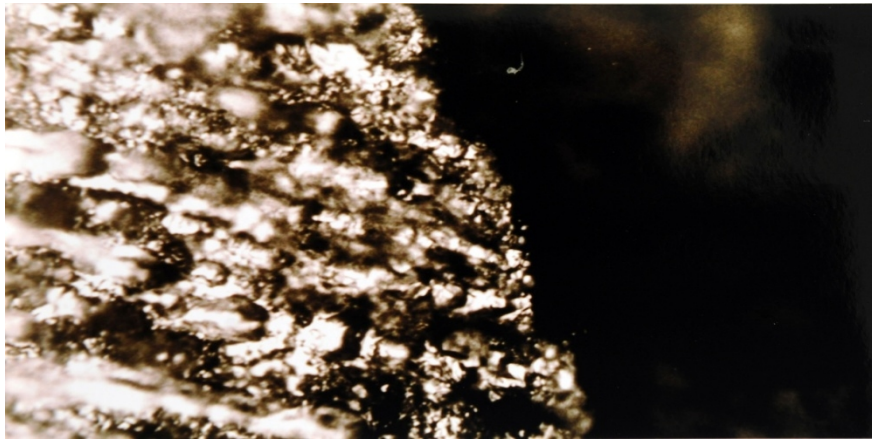


Figure 15: Photomicrograph of the Ni-Cr alloy/ceramic interface with fine grinding (P600C) followed by sandblasting of bare metal surface.(Magnification 200x4).

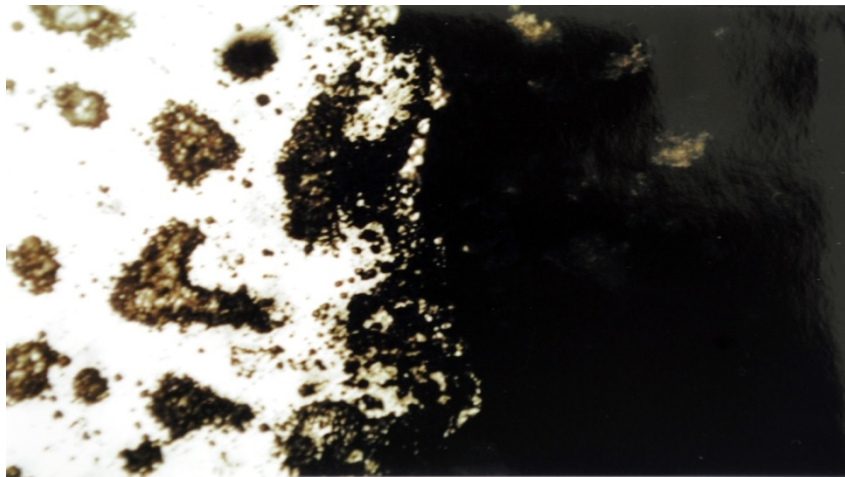


Figure 16: Photomicrograph of the Ni-Cr alloy/ceramic interface with sandblasting of bare metal surface.(Magnification 200x4).



Figure. 17: Photomicrograph of the Co-Cr alloy.(Magnification200x4).

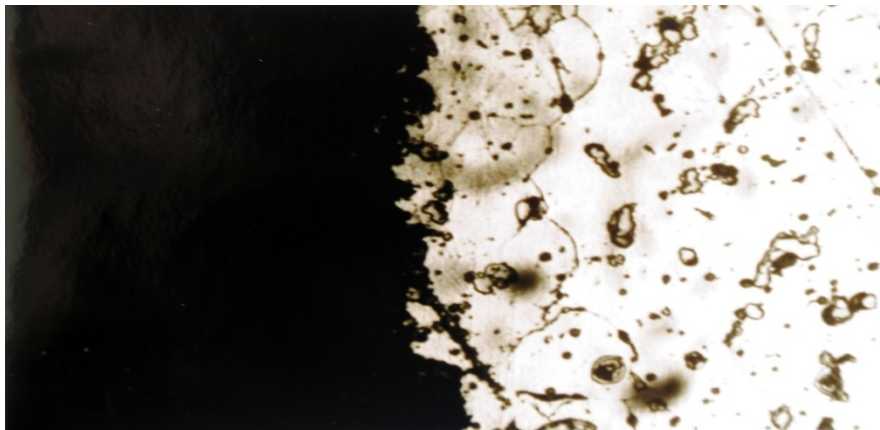


Figure 18: Photomicrograph of Co-Cr alloy/ceramic interface before metal surface treatment. (Magnification 200x4).

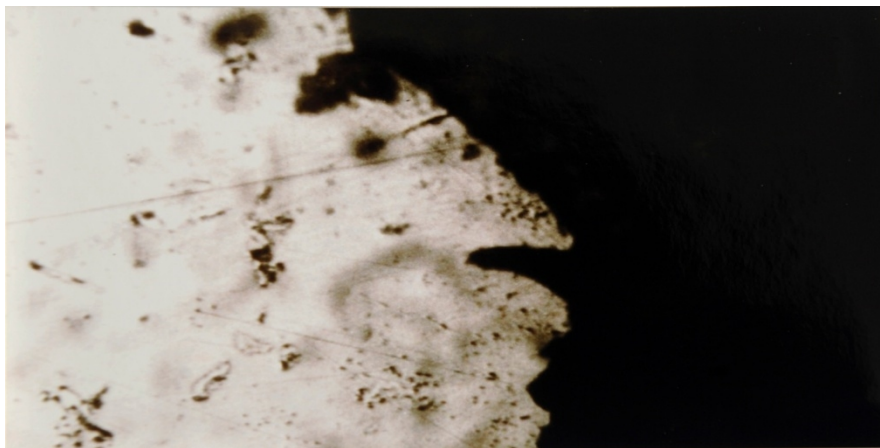


Figure 19: Photomicrograph of the Ni-Cr alloy/ceramic interface without metal surface treatment (Magnification 200x4).

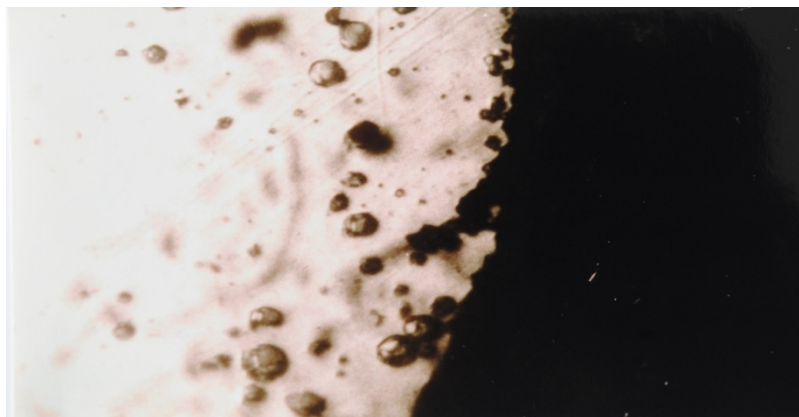


Figure 20: Photomicrograph of the Co-Cr alloy/ceramic interface with rough grinding (P120D).(Magnification 200x4).

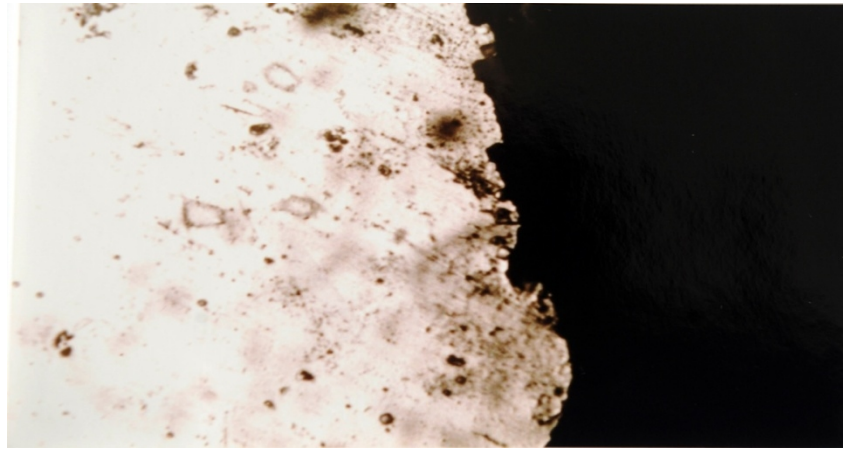


Figure 21: Photomicrograph of the Co-Cr alloy/ceramic interface with fine grinding (P600C). (Magnification 200x4).

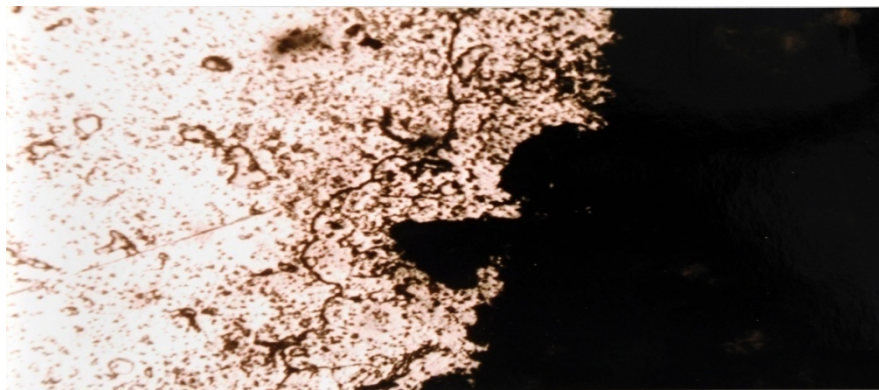


Figure 22: Photomicrograph of Co-Cr alloy/ceramic interface after rough grinding (P120D) followed by sandblasting. (Magnification 200 x 4)

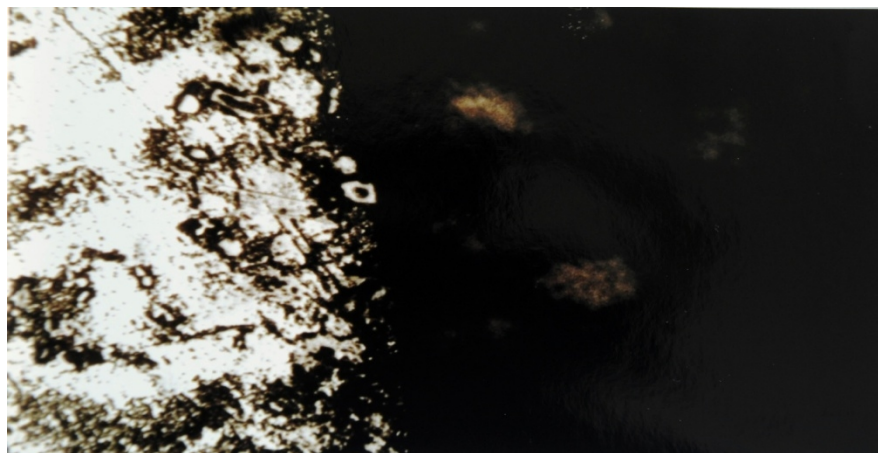


Figure 23: Photomicrograph of Co-Cr alloy/ceramic interface with fine grinding (P600C) followed by sandblasting. (Magnification 200 x 4)

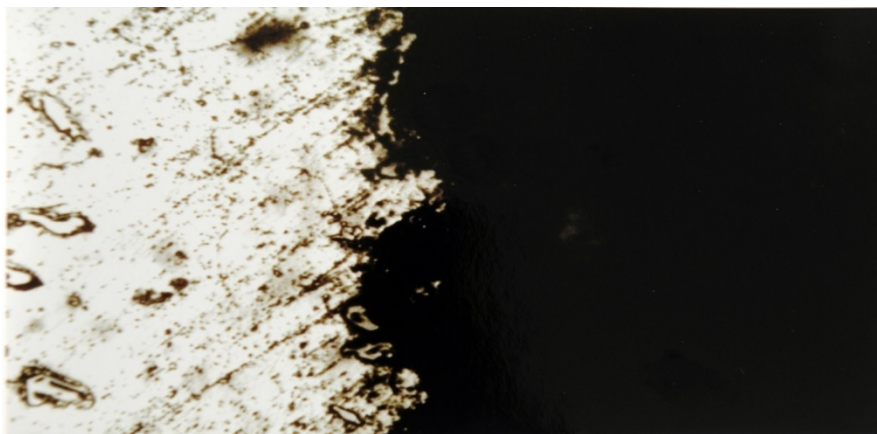


Figure 24: Photomicrograph of Co-Cr alloy/ceramic interface with sandblasting of bare metal surface. (Magnification 200 x 4).