ORIGINAL RESEARCH PAPER

Volume - 14 | Issue - 02 | February - 2025 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

AN IN VITRO STUDY TO EVALUATE THE SURFACE ROUGHNESS AND BOND STRENGTH OF PORCELAIN FUSED TO METAL RESTORATIONS FABRICATED BY DIFFERENT METHODS

Dentistry

Dr Srinivas Kalluri	MDS, Head of the Department, Department of Prosthodontics, GITAM Dental College and Hospital, Visakhapatnam.
Dr Chandana Seelam*	MDS, Department of Prosthodontics, GITAM Dental College and Hospital, Visakhapatnam. *Corresponding Author
Dr P Shameen Kumar	MDS, Professor, Department of Prosthodontics, GITAM Dental College and Hospital, Visakhapatnam.
Dr M Harikrishna	MDS, Professor, Department of Prosthodontics, GITAM Dental College and Hospital, Visakhapatnam.
Dr R Himabindu	MDS, Professor, Department of Prosthodontics, GITAM Dental College and Hospital, Visakhapatnam.
Dr Y Ravi Shankar	MDS, Professor, Department of Prosthodontics, GITAM Dental College and Hospital, Visakhapatnam.

ABSTRACT

Aim: The aim of the study was to evaluate the surface roughness and bond strength of porcelain fused to metal restorations fabricated by different methods. **Materials and Methods:** One hundred and twenty bar shaped samples of cobalt-chromium were fabricated by centrifugal casting, induction casting, direct metal laser sintering and milling containing thirty samples each. These samples were further divided into subgroups of which ten samples were served as control, ten samples were surface treated with Aluminium oxide particles, ten samples were surface treated with Silicon carbide particles. Samples were tested for surface roughness using Profilometer. Then samples were fired with porcelain and bond strength was measured using Universal testing machine. Results were analyzed using one-way ANOVA followed by Tukey multiple comparison test. **Results:** There was statistically significant difference among all four groups. The highest bond strength was seen in direct metal laser sintered samples followed by milling and induction casting and the least was found in centrifugal cast samples. Surface roughness was found highest in the samples abraded with silicon carbide particles followed by aluminium oxide particles. **Conclusion:** Within the limitations of the study, it can be concluded that laser sintered Co-Cr frameworks establish a strong bond with porcelain and also the metal-ceramic bond strength is dependent on the manufacturing method used and it was found that the bond strength values of all samples exceeded the minimum acceptable value of 25 MPa recommended by the ISO 9693.

KEYWORDS

Metal-ceramic, DMLS, Milling, Surface roughness, casting, Aluminium oxide, Silicon carbide, Bond strength, Cobalt-chromium, 3 point bend test

INTRODUCTION

Fixed dental prostheses can be fabricated using a variety of materials, including full ceramic restorations, porcelain fused to metal restorations, and metals including precious, semi-precious, and non-precious alloys.[1] The limitations of full ceramic and full metal restorations have led to a decline in demand, whereas porcelain fused to metal restorations have consistently maintained their status as the gold standard because of their outstanding durability and esthetic appearance. Porcelain has been fused to metal to fabricate restorations in order fulfil aesthetic requirements.[2]

Because of their superior good mechanical properties, metal ceramic bonding, biocompatibility, and capacity to create thinner, more rigid substructures, base metal alloys are frequently utilized in the fabrication of the metallic substrate for porcelain-fused-to-metal restorations. Irrespective of all alloy systems, the Co-Cr alloys have the highest modulus of elasticity.[1]

Metal-ceramic bonding is influenced by fabrication technique in along with material selection. The processes of centrifugal casting and induction casting are frequently employed in the production of metal copings. However, owing of its high melting range and tendency to generate unstable oxides that lead to bond failure at the interface, it is technique-sensitive. As a result, the additive technology of direct metal laser sintering (DMLS) and the subtractive technology of milling were created subsequently to help address laboratory errors. In direct metal laser sintering, using data files from the computer-aided design, metal powder is blasted selectively and fused with a laser to create a layer that is approximately 20–60 µm thick with each shooting in direct metal laser sintering. In milling, high efficiency in creating accurate geometries is seen, which is especially useful for long span restorations.[3]

A crucial aspect to take into consideration for the effectiveness of restoration is the ability of porcelain to adhere to metal. The debonding of porcelain from the metal substructure could result from improper bonding between the porcelain and metal.

Airborne-particle abrasion of bonding surfaces increases the metal surface energy by improving the wettability of the opaque ceramic and consequently, the bond strength, through micromechanical bonding. When it comes to air-abrasion particles, aluminium oxide (Al_2O_3) particles are the most often utilized. Silicon carbide particles are an alternative air-abrasion particles.[4]

With continuous evolution of techniques and materials, there arises a need to compare and evaluate the metal-ceramic bond strength, with metal alloys prepared by using the conventional method, induction casting, DMLS and Milling.

MATERIALS AND METHODS

In accordance with ISO standards, 120 cobalt-chromium samples measuring 25 x 3 x 0.5 mm were manufactured (Figure-1). Based on the fabrication process, these samples were divided into four categories.

The four groups were: Group-I: Metal substructure fabricated through centrifugal casting (n=30), Group II: Metal substructure fabricated through induction casting (n=30), Group-III: Metal substructure fabricated through Direct metal laser sintering (n=30), Group-IV: Metal substructure fabricated through Milling (n=30).

The samples from each group were further divided into three subgroups based on the type of surface treatment. Subgroup 1 – Control (n=10), Subgroup 2 – Samples abraded with Aluminium oxide particles (n=10), Subgroup 3 – Samples abraded with silicon carbide particles(n=10).

Fabrication of Metal Bars:

PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

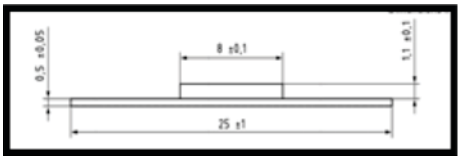


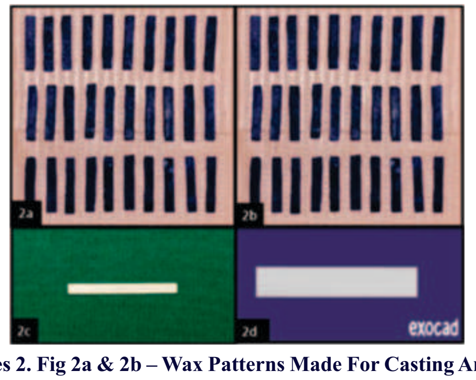
Figure 1 – Standardization Of Specimen

As per the ISO 9693 standardization, a stainless-steel die measuring 25×3×0.5 mm was created in order to create the casting specimens, for groups I and II. In order to make a mould to create the wax patterns, an imprint of this die was formed using putty (Aquasil, Dentsply, USA) (2 GM dental inlay wax). For both centrifugal and induction casting, sixty wax patterns were made and invested with phosphate-bonded investment powder (Bellavest SH). After that, an induction casting machine (Bego Fornax T) and a centrifugal casting machine were used to cast the Co-Cr alloy. To extract the castings, every casting ring was bench cooled, divested, and subjected to sandblasting.

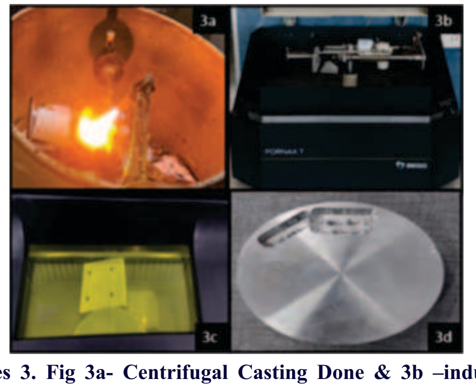
For DMLS specimens, design was prepared in CAD software (Exocad) and translated to standard tessellation language (stl) files, which were then sent to the DMLS equipment (DMP dental 100, US) for direct metal laser sintering (DMLS). The laser sintering system consisted of a radiation heater, a floor platform with metal powder on both sides that is movable by a piston, and a focussed laser beam at the roof. After evenly dispersing the extremely fine metal powder (EOS Cobalt Chrome SP2) throughout the platform, a 200-watt laser beam burned the metal nearby, fusing the powder to create the metal sample.

For milling samples, samples were generated using computer-aided design (CAD) software (Exocad Dental Cad, Exocad, Darmstadt, Germany) and they were subsequently exported to CAM software. In accordance with the manufacturer's specifications, the samples were milled using a milling machine (ARUM 5X-200, DOOWAN, Korea) from a prefabricated blank of cobalt-chromium alloy.

To achieve the appropriate dimensions, all of the samples were treated in the same manner using metal finishing points (Metal finishing and polishing kit – Shofu Inc.). To obtain rid of all the metal fragments, other debris, and grease that might have an impact on the wetting surface, they were then cleansed in distilled water for two to three minutes.



Figures 2. Fig 2a & 2b – Wax Patterns Made For Casting And Fig 2c –resin Prototype Made For Dmls Samples. Fig 2d – Stl File Made For Milling Samples



Figures 3. Fig 3a- Centrifugal Casting Done & 3b –induction Casting Done Fig 3c – Direct Metal Laser Sintering Done. Fig 3d –milling Of Metal Bars Done.

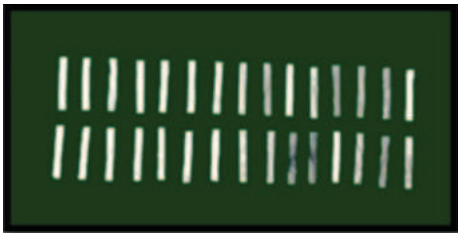


Figure 4 – Finished And Polished Cobalt-chromium Samples

Surface Treatment Of Samples

The samples in subgroup 1 remained untreated on their surfaces and were used as controls.

In subgroup 2, 110-microns aluminium oxide particles (Alminox-110) were used to abrade the samples by air for 10 seconds at a pressure of 0.2 MPa, while the samples were at a distance of 1 cm and an angle of 45^o. In subgroup 3, the samples were abraded for 10 seconds at a distance of 1 cm and an angle of 45^0 using 80-grit silicon carbide abrasive particles under 0.2 MPa of pressure. The surface roughness of each sample was measured with a contact profilometer (Mitutoyo SJ-201, Japan).

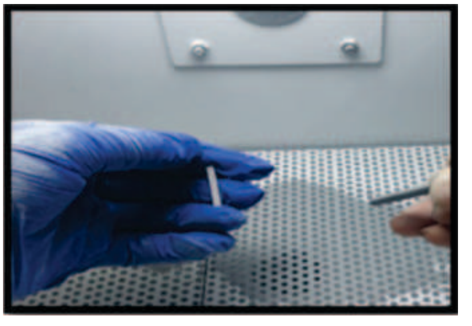


Figure 5 – Samples Placed In Sandblaster And Sandblasting Is Done

Figure 6 - Sample Is Placed On The Contact Profilometer For Checking Surface Roughness

Ceramic Layering

Layering was performed using an Ivoclar Vivadent AG, Liechtenstein, multi-layer leucite-containing veneering ceramic system (Ivoclar Vivadent IPS Inline ceramic system). Using the conventional ceramic building technique, two opaque ceramic layers with a maximum thickness of 0.1 mm each were applied at the centre of one side of each metal plate. The manufacturer's specified instructions for the furnace were followed in order to fire opaque ceramic. The final thickness of the opaque ceramic was between 0.1 and 0.2 mm. The applied ceramic area was rectangular and measured 8 x 3 mm. Next, the opaque layer was covered with the dentin layer, and firing was carried out in a ceramic furnace (VITA V) in accordance with the manufacturer's specifications.

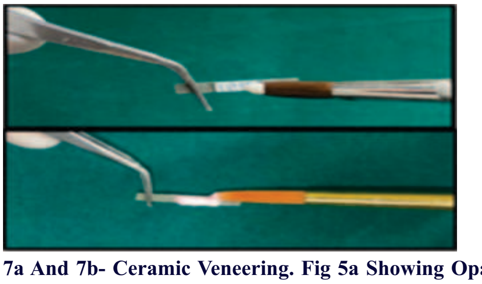


Figure 7a And 7b- Ceramic Veneering. Fig 5a Showing Opaque Layer Application & 5b Showing Dentin Layer Application

Figure 8 – Ceramic Firing Done In Ceramic Furnace

To determine the metal-ceramic bond strength, all 120 specimens underwent a three-point bending test, as advised by the current ISO specification 9693 and ANSI/ADA specification No. 38. A universal testing machine (Instron, UK) was used for this examination. A constant rate of cross-head speed of 1.5 mm/min was employed, and the force was recorded when fracture or separation of ceramic layer occurred (up to crack initiation). The load that led to the initial separation ofmaterials for each specimen was obtained in newton(N).

Figure 9 – Metal-ceramic Sample Placed In Universal Testing Machine For 3 Point Bend Test

RESULTS

Table 1: Surface Roughness Values Of Samples From All Groups After Surface Treatment

SURFACE ROUGHNESS		Mean	Std	F	P value
Centrifugal casting	Control group	1.85	0.45	29.257	0.000*
	Aluminium oxide	2.79	0.38		
	Silicon carbide	3.12	0.30		
Induction casting	Control group	1.57	0.43	32.902	0.000
	Aluminium oxide	2.70	0.37		
	Silicon carbide	2.83	0.33		
DMLS	Control group	2.48	0.33	63.351	0.000*
	Aluminium oxide	4.10	0.43		
	Silicon carbide	4.42	0.45		
Milling	Control group	1.58	0.46	3.218	0.056*
	Aluminium oxide	1.88	0.42		
	Silicon carbide	2.03	0.31		

One-way ANOVA; * statistically significant

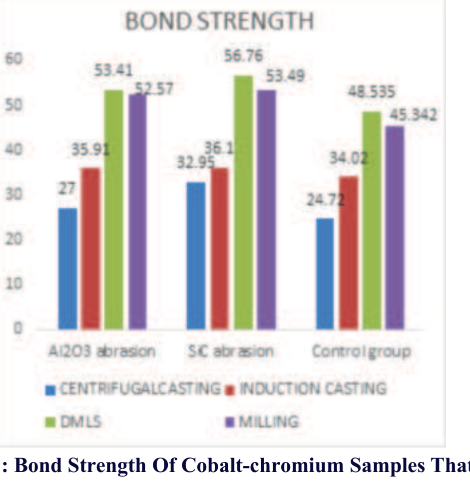
Table 2: Bond Strength Values Of Samples From All Groups After Ceramic Veneering

BOND STRENGTH		Mean	Std	F	P value
Centrifugal casting	Control group	24.72	4.39	9.915	0.001*
	Aluminium oxide	27.00	3.85		
	Silicon carbide	32.95	4.52		
Induction casting	Control group	34.02	2.54	2.548	0.097
	Aluminium oxide	35.91	2.33		
	Silicon carbide	36.10	1.93		
DMLS	Control group	49.39	4.92	33.341	0.000*
	Aluminium oxide	54.91	2.63		
	Silicon carbide	59.16	2.98		
Milling	Control group	46.06	3.30	4.687	0.018*
	Aluminium oxide	52.94	2.83		
	Silicon carbide	53.49	3.61		

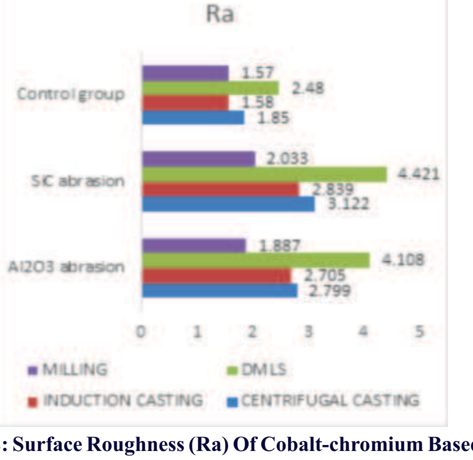
One-way ANOVA; * statistically significant

One way ANOVA was used to statistically analyse the data. When cobalt-chromium metal samples were subjected to Silicon carbide and aluminium oxide abrasion, the surface roughness (Ra) of the samples showed a statistically significant difference (P = 0.000) across the four groups. When the surface roughness was compared between the groups, DMLS had the greatest mean surface roughness (4.421), followed by centrifugal casting (3.122), induction casting (2.83), and samples made by milling (2.03).

When the surface roughness was compared between the subgroups, the samples abraded with silicon carbide particles had the highest mean surface roughness (4.421±0.45), followed by samples abraded with aluminium oxide particles (4.100±0.43), and the samples used as controls had the lowest mean surface roughness (2.48±0.33). When the groups' mean bond strengths were examined, the samples made using the DMLS method had the highest bond strength (59.16±2.98), followed by those made using milling (53.46±3,61) and induction casting (36.10±1.93), while the samples made using centrifugal casting had the lowest bond strength (32.95±4.52). When the bond strength was compared between the subgroups, the samples that were abraded with silicon carbide particles had the highest mean bond strength, followed by samples that were abraded with aluminium oxide particles.



Graph 1: Bond Strength Of Cobalt-chromium Samples That Are Fused To Porcelain (Based On Surface Treatment And The Method Of Fabrication)



Graph 2: Surface Roughness (Ra) Of Cobalt-chromium Based On

Type Of Treatment And The Fabrication Method

DISCUSSION

Over thirty to forty years, dentists have employed metal-ceramic prosthesis. Their optimal selection is vital since it is known that the metal-ceramic bonding depends on the chemical interaction between the metal alloy and the ceramic. Co-Cr base metal alloys are the most commonly used alloys. Thus, the alloys chosen were aimed to represent popular choices made. There are a number of methods available for fabricating metal substructures in addition to alloy selection. DMLS and Milling having advantage of fabrication of restorations with a uniform quality and high precision was used to compare with the casting techniques.

Porcelain bond strength to metal alloys can be measured using a variety of test methods. Commonly used tests include shear, tensile, combination shear-tension, bending (flexure), and torsion tests. There are limitations to every testing procedure when it comes to determining bond strength. To determine porcelain bond strength to dental alloys, the ISO 9693-2012 test standard, however, recommends a 3-point bending test since it more closely resembles clinical settings because the specimens are simultaneously subjected to traction, shear bond strength, and compression.[5]

Our investigations findings showed that samples made by direct metal laser sintering had the strongest metal-ceramic bond strength followed by milling and induction casting and the least was found in samples fabricated by centrifugal casting. The samples that were abraded with silicon carbide particles had the maximum surface roughness, whereas those that were abraded with aluminium oxide particles had the least amount of roughness. In comparison with the other groups, samples made using direct metal laser sintering were found to have the highest surface roughness. Thus, surface treatment and fabrication method influence the strength of the metal-ceramic bond.

The type of abrasive employed during processing is likely the cause of the increased surface roughness seen in samples abraded with silicon carbide particles. It is related to the hardness and shape of the particles; rounded abrasive particles provide surface roughness that is wider and shallower than that of sharper abrasive particles. The rounded shape of aluminium oxide particles results in an uneven surface with greater width but less depth, whereas the sharp shape of silicon carbide particles creates an uneven surface with greater depth that requires more machining of the processed material and produces surfaces with more developed roughness profiles[6,7]

Direct metal laser sintering (DMLS) can result in some overlapping between adjacent films and columnar grains along the build axis, which is controlled by directional cooling. This can lead to increased surface roughness.[8,9] In addition, compared to other groups, the DMLS samples had a stronger bond because of their dense and directed microstructure and the interdiffusion of metal oxides into the opaque ceramic, which is a crucial aspect of chemical bonding. [10]

The flat surface of sandblasted samples with slot-like pores and small notches may be the cause of the decreased surface roughness in induction cast samples. Reduced surface roughness in induction cast base metal alloys has been linked to lower physicochemical properties than laser-sintered Co-Cr. [11] Therefore, direct metal laser sintering presents itself as a viable substitute for casting.

When compared to centrifugal and induction casting, the increased bond strength in milled materials may be attributed to their increased stiffness and Young's modulus. The second phase particles, porosity, and grain size all contribute to this varied mechanical performance. The so-called "second-phase strengthening effect" occurs when massive dislocation loops are formed by the second phase, which inhibits dislocation motion and increases the alloy's resistance to deformation. One significant disadvantage of casting is porosity. The inhomogeneous appearance and many pores seen in the casting specimens are linked to dendritic structure and shrinkage that occurs during the solidification of the Co-Cr alloy casting. Dendritic segregation causes differences in the solute distribution between the dendritic and interdendritic zones, which may lessen the mechanical characteristics. The milling group, on the other hand, exhibited a dense, uniform structure devoid of pores. The fracture surfaces of the milling specimens show some rip ridges and are dense, free of significant internal flaws, suggesting a very ductile fracture. The blanks were produced industrially in an efficient and regulated procedure for the milling group. This might be an explanation for the superior mechanical properties of the milling. The casting group revealed the lowest bond strength between alloy and ceramic, which might be partially attributed to the lowest rigidity. The casting group showed a defected appearance with some cleavage planes, which indicated a typical brittle fracture behaviour with poor ductility.[12]

The samples produced using centrifugal casting had the lowest bond strength, which might be attributed to the production of bubbles and the thickness of the oxide layer. Whenever bubbles form in the specimens, the alloy's undercut surface becomes sharp, and if the porcelain isn't properly wetted, air and other contaminants may be trapped, forming porosity in the porcelain during the sintering process and weakening the bond.[13] Bond strength is known to be strongly associated with oxide layer thickness. An oxide layer that is thin, non-existent, or overly thick will lead to a weak connection. The bond strength of the centrifugal cast group was lowest, attributed partially to the greatest oxide layer thickness[14].

LIMITATIONS

1. The oral environment, including changes in temperature, pH, moisture, saliva content, and bacterial presence, was not simulated.
2. Variations in masticatory loading can lead to changes in mechanical characteristics.

CONCLUSION

The following conclusions have been drawn within the limitations of the present investigation.

1. The cobalt-chromium samples fabricated by Direct metal laser sintering showed highest bond strength followed by milling, induction casting and the least was found in centrifugal casting.
2. The cobalt-chromium samples fabricated by Direct metal laser sintering showed highest surface roughness followed by centrifugal casting, induction casting and the least was found in the samples fabricated by milling.
3. The cobalt-chromium samples abraded with silicon carbide particles showed highest surface roughness and bond strength followed by aluminium oxide particles.

REFERENCES

1. Prasad MN, Jyoti NB, Sabita RM. A comparative evaluation of shear bond strength of porcelain fused to metal substructure fabricated using conventional and contemporary techniques: an in vitro study. INTERNATIONAL JOURNAL OF MEDICAL RESEARCH & HEALTH SCIENCES. 2015 Jan 1;4(1):186-92.
2. Makhija SK, Lawson NC, Gilbert GH, Litaker MS, McClelland JA, Louis DR, Gordan VV, Pihlstrom DJ, Meyerowitz C, Mungia R, McCracken MS. Dentist material selection for single-unit crowns: Findings from the National Dental Practice-Based Research Network. Journal of dentistry. 2016 Dec 1;55:40-7.
3. Kassapidou M, Franke Stenport V, Hjalmarsson L, Johansson CB. Cobalt-chromium alloys in fixed prosthodontics in Sweden. Acta biomaterialia odontologica Scandinavica. 2017 Jan 1;3(1):53-62.
4. Wolowiec-Korecka E, Czepulkowska-Pawlak W, Kula Z, Klimek L. Effect of SiC Abrasive Blasting Parameters on the Quality of the Ceramic and Ni-Cr Dental Alloy Joint. Materials. 2022 Jan 26;15(3):964.
5. International Organization for Standardization. ISO 9693-1. Dentistry Compatibility testing - Part 1: Metal-ceramic systems. Geneva: International Organization for Standardization; 2012
6. Czepułkowska-Pawlak W, Wołowiec-Korecka E, Klimek L. The Surface Condition of Ni-Cr after SiC Abrasive Blasting for Applications in Ceramic Restorations. Materials. 2020 Dec 21;13(24):5824.
7. Taga, Y.; Kawai, K.; Nokubi, T. New method for divesting cobalt-chromium alloy castings: Sandblasting with a mixed abrasive powder. J. Prosthet. Dent. 2001, 85, 357–362.
8. Lövgren N, Roxner R, Klemendz S, Larsson C. Effect of production method on surface roughness, marginal and internal fit, and retention of cobalt-chromium single crowns. The Journal of Prosthetic Dentistry. 2017 Jul 1;118(1):95-101.
9. Castillo-Oyagüe R, Osorio R, Osorio E, Sánchez-aguilera F, Toledano M. The effect of surface treatments on the microroughness of laser-sintered and vacuum-cast base metal alloys for dental prosthetic frameworks. Microscopy research and technique. 2012 Sep;75(9):1206-12.
10. Kaleli N, Saraç D. Comparison of porcelain bond strength of different metal frameworks prepared by using conventional and recently introduced fabrication methods. The Journal of Prosthetic Dentistry. 2017 Jul 1;118(1):76-82.
11. Akova T, Ucar Y, Tukay A, Balkaya MC, Brantley WA. Comparison of the bond strength of laser-sintered and cast base metal dental alloys to porcelain. Dental materials. 2008 Oct 1;24(10):1400-4.
12. Han X, Sawada T, Schille C, Schweizer E, Scheideler L, Geis-Gerstorfer J, Rupp F, Spintzyk S. Comparative analysis of mechanical properties and metal-ceramic bond strength of Co-Cr dental alloy fabricated by different manufacturing processes. Materials. 2018 Sep 22;11(10):1801.
13. Wang H, Feng Q, Li N, Xu S. Evaluation of metal-ceramic bond characteristics of three dental Co-Cr alloys prepared with different fabrication techniques. The Journal of prosthetic dentistry. 2016 Dec 1;116(6):916-23.
14. Lombardo GH, Nishioka RS, Souza RO, Michida SM, Kojima AN, Mesquita AM, Buso L. Influence of surface treatment on the shear bond strength of ceramics fused to cobalt–chromium. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2010 Feb;19(2):103-11.