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# The effect of repeated firing on shear bond and flexural strength of nickel-chromium porcelain-fused-to-metal restorations: a systematic review

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***Abstract:*** *Objective: This systematic review aimed to evaluate the effect of repeated porcelain firing cycles on the shear bond strength and flexural bond strength of nickel–chromium (Ni-Cr) porcelain-fused-to-metal restorations. Methods: This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Literature searches were conducted in Scopus, Crossref, Google Scholar, and Semantic Scholar databases using Publish or Perish software version 8. The search included studies published between January 2015 and December 2025. Keywords related to repeated firing, nickel–chromium alloy, porcelain-fused-to-metal restorations, shear bond strength, and flexural strength were applied using Boolean operators. Articles were screened through title, abstract, and full-text evaluation according to predetermined inclusion and exclusion criteria. Data from eligible studies were extracted and synthesized qualitatively. Results: A total of 2,412 records were initially identified, and after the screening and eligibility process, 21 studies were included in the qualitative synthesis. The reported shear bond strength (SBS) values ranged from approximately 13 MPa to 65 MPa, depending on alloy composition, surface treatment, manufacturing technique, and firing cycles. Flexural bond strength values measured using the three-point bending test according to ISO 9693 ranged from approximately 20 MPa to 25 MPa. Most studies indicated that repeated firing cycles within the conventional clinical range had minimal influence on bond strength. However, excessive firing cycles or repeated alloy recasting could lead to gradual reductions in bond strength due to alterations in oxide layer formation and interfacial characteristics. Conclusion: Repeated porcelain firing cycles generally have limited effects on the mechanical properties of Ni-Cr porcelain-fused-to-metal restorations when performed within standard laboratory procedures. Most reported bond strength values met or approached the minimum requirements specified by ISO 9693, indicating that Ni-Cr metal–ceramic restorations remain mechanically reliable for clinical applications.*
***Keywords:*** *Repeated firing; Metal–ceramic bond strength; Flexural strength; Nickel-chromium alloy; Porcelain-fused-to-metal restorations.*

**Abstrack:** Tujuan: Tinjauan sistematis ini bertujuan untuk mengevaluasi pengaruh siklus pemanggangan ulang porselen terhadap kekuatan ikatan geser (shear bond strength) dan kekuatan ikatan lentur (flexural bond strength) pada restorasi logam-keramik nikel–kromium (Ni-Cr) yang dilapisi porselen. Metode: Penelitian ini mengikuti pedoman Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Pencarian literatur dilakukan di basis data Scopus, Crossref, Google Scholar, dan Semantic Scholar menggunakan perangkat lunak Publish or Perish versi 8. Pencarian mencakup studi yang dipublikasikan antara Januari 2015 hingga Desember 2025. Kata kunci yang terkait dengan pemanggangan ulang, paduan nikel–kromium, restorasi logam-keramik, kekuatan ikatan geser, dan kekuatan lentur diterapkan menggunakan operator Boolean. Artikel diseleksi melalui evaluasi judul, abstrak, dan teks lengkap sesuai dengan kriteria inklusi dan eksklusi yang telah ditetapkan. Data dari studi yang memenuhi syarat kemudian diekstraksi dan disintesis secara kualitatif. Hasil: Sebanyak 2.412 catatan awal diidentifikasi, dan setelah proses penyaringan dan penilaian kelayakan, 21 studi dimasukkan dalam sintesis kualitatif. Nilai kekuatan ikatan geser (SBS) yang dilaporkan berkisar antara ±13 MPa hingga 65 MPa, tergantung pada komposisi paduan, perlakuan permukaan, teknik manufaktur, dan jumlah siklus pemanggangan. Nilai kekuatan ikatan lentur yang diukur menggunakan uji lentur tiga titik sesuai ISO 9693 berkisar antara ±20 MPa hingga 25 MPa. Sebagian besar studi menunjukkan bahwa siklus pemanggangan ulang dalam rentang klinis konvensional memiliki pengaruh minimal terhadap kekuatan ikatan. Namun, siklus pemanggangan yang berlebihan atau pencetakan ulang paduan secara berulang dapat menyebabkan penurunan bertahap dalam kekuatan ikatan akibat perubahan pada pembentukan lapisan oksida dan karakteristik antarmuka. Kesimpulan: Siklus pemanggangan ulang porselen umumnya memiliki efek terbatas terhadap sifat mekanis restorasi logam-keramik Ni-Cr bila dilakukan sesuai prosedur laboratorium standar. Sebagian besar nilai kekuatan ikatan yang dilaporkan memenuhi atau mendekati persyaratan minimum yang ditentukan oleh ISO 9693, menunjukkan bahwa restorasi logam-keramik Ni-Cr tetap andal secara mekanis untuk aplikasi klinis.
**Kata Kunci:** Pemanggangan ulang; Kekuatan ikatan logam–keramik; Kekuatan lentur; Paduan nikel–kromium; Restorasi porselen-keramik pada logam.

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## INTRODUCTION

Metal-ceramic restorations, particularly porcelain-fused-to-metal (PFM) restorations, have long been used in prosthodontics due to their favorable combination of mechanical strength, durability, and esthetic properties. These restorations combine the high strength and stiffness of metal alloys with the natural appearance of dental porcelain, enabling them to withstand occlusal forces while maintaining acceptable esthetics (Mariusz et al., 2019). Among the available metal alloys, nickel-chromium (Ni-Cr) alloys are commonly used due to their high modulus of elasticity, corrosion resistance, and relatively lower cost compared to noble metal alloys (Kamath et al., 2022).

The clinical success of metal-ceramic restorations largely depends on the integrity of the bond between the metal framework and the porcelain veneer. An adequate bond prevents chipping, cracking, or delamination of the porcelain veneer during mastication. The bonding mechanism between metal and ceramic involves chemical bonding through the formation of an oxide layer, mechanical interlocking, and compressive stress generated by the compatible coefficients of thermal expansion between the two materials(Dawod et al., 2023).

Therefore, evaluating mechanical properties such as shear bond strength and flexural strength is crucial for assessing the accuracy of metal-ceramic systems. During the fabrication of PFM restorations, porcelain veneers typically require multiple firing cycles to achieve the desired aesthetic contour and color harmony. However, repeated firing cycles can affect the metal-ceramic interface by altering oxide-layer formation, thermal-stress distribution, and the material's microstructural characteristics. Research by Nair et al. (2016) showed that firing 3, 5, and 7 times did not significantly affect the shear bond strength between porcelain and alloy-based metal (Nair, Hegde, and Vallabhaneni, 2016). Previous studies have reported inconsistent findings regarding the effect of repeated firing on the mechanical performance of metal-ceramic restorations, particularly regarding shear bond strength and flexural strength. Furthermore, these properties play a crucial role in preventing porcelain fracture and ensuring the long-term durability of the restoration (Hashem, Raiesa Mohamed and Kotb Salem, 2023).

Therefore, this systematization aims to highlight the influence of repeated firing cycles on the shear bond strength and flexural strength of nickel-chromium fused-to-metal porcelain restorations by synthesizing available evidence from experimental and in vitro studies.

## METHOD

1.Identification of Articles

The identification of articles was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a transparent and systematic process. The objective of this systematic review is to evaluate the effect of repeated porcelain firing cycles (intervention) compared with conventional firing procedures (comparison) on the shear bond strength and flexural strength (outcomes) of nickel–chromium porcelain-fused-to-metal restorations (population).

A comprehensive literature search was performed using several electronic databases, including Crossref, Semantic Scholar, Google Scholar, and Scopus. The search process was assisted by Publish or Perish software version 8 to retrieve and manage relevant publications. The search covered studies published between January 2015 and December 2025.

The search strategy used combinations of relevant keywords and Boolean operators, such as:"repeated firing" OR "multiple firing.", "nickel chromium" OR "Ni-Cr alloy.""porcelain fused to metal" OR "PFM restoration." "shear bond strength." "flexural strength." These keywords were combined using AND and OR to obtain relevant studies examining the effect of repeated firing on the mechanical properties of Ni-Cr porcelain-fused-to-metal restorations, particularly shear bond strength and flexural strength.

2.Selection of Articles

All articles obtained from the database search were exported and compiled into a reference list. Duplicate records identified across the databases were removed. The selection process was conducted in several stages. First, titles and abstracts were screened to determine their relevance to the research topic. Articles that clearly did not relate to repeated firing, Ni-Cr alloys, porcelain-fused-to-metal restorations, shear bond strength, or flexural strength were excluded at this stage. Studies that met the initial screening criteria were then reviewed in full text to further evaluate their relevance and suitability for inclusion in the review.

3.Eligibility of Articles

Full-text articles that passed the selection stage were assessed for eligibility based on predetermined inclusion and exclusion criteria.

The inclusion criteria were:

a. Articles published between 2015 and 2025.
b. Studies investigating nickel-chromium (Ni-Cr) alloys used in porcelain-fused-to-metal restorations.
c. Studies evaluating the effect of repeated or multiple firing on mechanical properties, particularly shear bond strength or flexural strength.
d. Experimental or laboratory studies relevant to dental materials.
e. Articles published in English and available in full text.

The exclusion criteria were:

a. Review articles, editorials, letters, or conference abstracts without full experimental data.

b. Studies not involving Ni-Cr alloys or porcelain-fused-to-metal restorations.
c. Studies that did not evaluate shear bond strength or flexural strength.
d. Articles with incomplete data or unavailable full text.

The final set of eligible studies was then included for qualitative analysis in this systematic review.

4.Data Extraction and Data Analysis

**Data Extraction**

Data extraction was performed systematically from all eligible studies included in this review. Two independent reviewers conducted the extraction process to minimize bias and ensure accuracy. Any discrepancies between the reviewers were discussed and resolved through consensus.

The following information was extracted from each selected study:

a. Author(s) and year of publication
b. Study design and experimental method
c. Type of metal alloy used nickel-chromium alloy specifications
d. Porcelain system used in the PFM restoration
e. Number of firing cycles (repeated firing conditions)
f. Sample size
g. Type of mechanical test performed (shear bond strength or flexural strength test)
h. Testing standards or methods used (according to ISO 9693)
i. Main findings related to bond strength or flexural strength
j. Conclusions reported by the authors

All extracted data were compiled and organized in a data extraction table to facilitate comparison and synthesis of the findings across the included studies.

**Data Analysis**

The collected data were analyzed using a qualitative descriptive approach. The results of the selected studies were compared and synthesized to identify patterns, similarities, and differences regarding the effect of repeated firing on the shear bond strength and flexural strength of nickel-chromium porcelain-fused-to-metal restorations. The analysis focused on:

a. The number of firing cycles applied in each study
b. The type of Ni-Cr alloy and porcelain system used
c. The mechanical testing methods applied
d. The reported bond strength and flexural strength values

The findings from the included studies were then summarized and interpreted to provide a comprehensive understanding of how repeated firing influences the mechanical properties of Ni-Cr porcelain-fused-to-metal restorations. The synthesized results were presented in tables and narrative form to facilitate interpretation and discussion.

## RESULT AND DISCUSSION

A total of 2,412 records were initially identified through database searching. The records were obtained from Scopus (n = 429), Crossref (n = 1,000), Google Scholar (n = 207), and Semantic Scholar (n = 776). Before the screening stage, 2,320 articles were excluded because they did not meet the research topic. Additional exclusions included duplicate records (n = 17) and one article with incomplete text, resulting in 91 articles remaining for screening. Following the title and abstract screening, 51 articles were excluded because they did not meet the inclusion criteria. Consequently, 26 articles were assessed for full-text eligibility. During the eligibility assessment, five studies were excluded due to several reasons, including review articles, editorials, letters, or conference abstracts without full experimental data; studies not involving nickel–chromium alloy or porcelain-fused-to-metal restorations; studies that did not evaluate shear bond strength or flexural strength; and articles with incomplete data or unavailable full text. Finally, 21 studies met all eligibility criteria and were included in the qualitative synthesis of this systematic review.

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Table 1. General characteristics of the selected studies

| NO | Author | Year | Alloy | Firing Cycles | Test Method: Bond Strength (MPa) & Flexural Strength (MPa) | Sample Size | Results | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 1 | Farzin et al. | 2018 | Ceramill Sintron Co-Cr alloy and conventional Ni-Cr alloy (4-all) | 3, 5, and 7 firing cycles | Shear bond strength test (UTM); Ceramill Sintron ≈ 42.87 MPa, 4-all ≈ 22.48 MPa | 36 specimens | Number of porcelain firing cycles had no significant effect on shear bond strength | Multiple porcelain firings do not significantly influence metal–ceramic bond strength |
| 2 | Yadav et al. | 2019 | Ni-Cr alloy (Bella bond plus) | Not specified (repair system evaluation) | Shear bond strength test using universal testing machine; SBS ≈ 29.16 MPa (Clearfil) and 27.23 MPa (P&R system) | 90 specimens | Clearfil repair system produced higher SBS in cohesive fractures while P&R system showed higher SBS in adhesive fractures | Repair material influences the bond strength of repaired metal–ceramic restorations |
| 3 | Jhansi et al. | 2019 | Ni-Cr alloys (NDN, Soft alloy, Superbond) | Recasting vs new alloy | Flexural bond strength evaluated by three-point bending test according to ISO 9693 | 60 specimens | Bond strength values were above the minimum requirement of ISO 9693, although recycled alloys showed slightly lower values | Recycled Ni-Cr alloys remain clinically acceptable but may reduce bond strength compared with new alloys |
| 4 | Abrisham et al. | 2017 | Ni-Cr alloy (4all) and Zirconia | Conventional porcelain firing | Shear Bond Strength test using universal testing machine; PFM ≈ 24.57 MPa, PFZ ≈ 20.88 MPa | 30 specimens | Mean SBS of PFM restorations was higher than zirconia-based restorations, but the difference was not statistically significant | Both PFM and zirconia systems showed comparable bond strength performance |
| 5 | Kamath et al. | 2022 | Ni-Cr alloy (Wiron 99) and Co-Cr alloy (Wironit) | Conventional porcelain firing | Shear Bond Strength test; Ni-Cr group ≈ 47.1–65.6 MPa depending on surface treatment | 80 specimens | Shear bond strength was significantly influenced by alumina particle size used for sandblasting | Surface treatment and oxidation heat treatment influence metal–ceramic bond strength |
| 6 | Sreekala et al. | 2015 | Ni-Cr alloy (Bellabond plus) and zirconia | Conventional firing with aging simulation | Shear Bond Strength test; base metal alloy before aging ≈ 39.51 MPa, after aging ≈ 37.20 MPa | 40 specimens | Porcelain veneered base metal alloys showed higher SBS than zirconia groups; aging reduced SBS values | Aging influences bond strength, but metal–ceramic restorations maintain higher SBS compared to zirconia systems |

| NO | Author | Year | Alloy | Firing Cycles | Test Method: Bond Strength (MPa) & Flexural Strength (MPa) | Sample Size | Results | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 7 | Ahmed & Alwahab | 2022 | Ni-Cr alloy | Conventional porcelain firing | Shear Bond Strength test; sandblast + acid etching ≈ 26.11 ± 1.85 MPa | 21 specimens | Combination surface treatment produced the highest SBS compared with individual treatments | Combined mechanical and chemical surface treatments improve bonding between Ni-Cr alloy and porcelain |
| 8 | Bahri et al. | 2020 | Ni-Cr, Co-Cr, Zirconia, Lithium Disilicate | Multiple porcelain firing cycles during veneering (opaque and dentin layers) | Shear Bond Strength (SBS). Zirconia: 34.6 MPa; Co-Cr: 30.66 MPa; Ni-Cr: 30.58 MPa; Lithium disilicate: 20.05 MPa | 48 specimens (4 groups ×12) | Zirconia showed the highest SBS followed by Co-Cr and Ni-Cr alloys, while lithium disilicate showed the lowest values. | No statistically significant difference in SBS among the tested materials. |
| 9 | Mohammadi et al. | 2021 | Casting Ni-Cr, Casting Co-Cr, CAD/CAM milled-sintered Co-Cr (Sintron) | Standard porcelain firing cycles | Three-point flexural bond strength test (ISO 9693). Sintron Co-Cr: 24.58±5.16 MPa; Ni-Cr casting: 21.13±6.34 MPa; Co-Cr casting: 20.98±4.84 MPa | 63 specimens (3 groups ×21) | Milled-sintered Co-Cr showed significantly higher bond strength compared to casting alloys. | CAD/CAM milled-sintered Co-Cr alloy can be a suitable alternative to conventional casting alloys. |
| 10 | Chanu et al. | 2025 | Ni-Cr alloy with different recasting ratios | Standard ceramic firing after oxidation heat treatment | Shear Bond Strength (SBS). C0: 64.65 MPa; C1: 58.8 MPa; C2: 46.3 MPa | 108 specimens (6 groups ×18) | Bond strength decreased with repeated recasting of Ni-Cr alloy. Fresh alloy showed the highest SBS values. | Recasting beyond the first generation significantly reduces metal–ceramic bond strength. |
| 11 | Albarudi & Alsalameh | 2020 | Ni-Cr alloy | 3, 5, and 7 firing cycles | Shear Bond Strength test; Group A: 56.90 MPa, Group B: 51.69 MPa, Group C: 43.54 MPa | 30 specimens | Significant decrease in shear bond strength as the number of firing cycles increased | Repeated firing cycles significantly affect the bond strength of porcelain fused to metal restorations |
| 12 | Oak et al. | 2024 | Ni-Cr alloy (Wirocer Plus) | Conventional firing | Shear Bond Strength test; highest mean SBS 13.39 ± 0.66 MPa for adhesive defect repair | 96 specimens | Different porcelain repair systems showed different SBS and color stability values | Selection of appropriate repair system is essential to improve bond strength in repaired PFM restorations |

| NO | Author | Year | Alloy | Firing Cycles | Test Method: Bond Strength (MPa) & Flexural Strength (MPa) | Sample Size | Results | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 13 | Patil & Shetty | 2018 | Ni-Cr alloy | Conventional porcelain firing | Shear Bond Strength test; veneering technique 25.06 MPa, press technique 21.68 MPa | 10 specimens | Veneering technique produced higher bond strength than pressable ceramic technique | Fabrication technique influences metal-ceramic bond strength in PFM restorations |
| 14 | Ahmed & Alwahab | 2022 | Ni-Cr alloy | Conventional firing | Shear Bond Strength test using universal testing machine; combination treatment 26.11 ± 1.85 MPa, acid etch 22.02 ± 1.5 MPa, sandblast 20.85 ± 1.5 MPa | 21 specimens | Combination of sandblasting and acid etching produced the highest SBS compared to other surface treatments | Surface treatment significantly influences the bond strength between Ni-Cr alloy and porcelain veneer |
| 15 | Nair et al. | 2016 | Ni-Cr alloy and Co-Cr alloy | 3, 5, and 7 firing cycles | Shear Bond Strength test using universal testing machine | 60 specimens | No statistically significant difference in SBS after repeated firings; Ni-Cr showed higher bond strength than Co-Cr | Multiple firings did not significantly affect metal–ceramic bond strength |
| 16 | Prasad et al. | 2015 | Cast Ni-Cr, Cast Co-Cr, Laser-sintered Co-Cr | Standard porcelain firing cycles with feldspathic porcelain | Shear Bond Strength (SBS) using Universal Testing Machine | 30 specimens (3 groups ×10) | Laser-sintered Co-Cr alloy showed the highest SBS, followed by cast Ni-Cr and cast Co-Cr alloys. | Laser sintering technique improves metal-ceramic bond strength compared with conventional casting methods. |
| 17 | Al Jabbari et al. | 2016 | Ni-Cr-Be alloy | Conventional firing with thermocycling | Debonding load evaluated using universal testing machine; bond strength measured after surface treatment | 80 specimens | Metal Primer II and Rocatec systems significantly improved bond strength compared to untreated surfaces | Surface treatment plays a critical role in improving bonding between Ni-Cr alloy and acrylic resin materials |
| 18 | Priya et al. | 2025 | Ni-Cr alloy (Wiron Light) | Recasting cycles (A0–A4 groups) | Three-point flexural test to evaluate bond and fracture strength | 100 specimens | The highest bond strength was observed in the control group (100% new alloy), while repeated recasting reduced bond strength | Use of fresh alloy provides higher metal-ceramic bond strength compared to recycled alloy |

| NO | Author | Year | Alloy | Firing Cycles | Test Method: Bond Strength (MPa) & Flexural Strength (MPa) | Sample Size | Results | Conclusion |
|---|---|---|---|---|---|---|---|---|
| 19 | Albarudi & Alsalameh | 2020 | Ni-Cr alloy | 3, 5, and 7 firing cycles | Shear Bond Strength test using universal testing machine | 30 specimens | Mean SBS values decreased with increasing firing cycles (56.9 MPa → 43.54 MPa) | Repeated firing cycles significantly reduce the shear bond strength of porcelain-fused-to-metal restorations |
| 20 | Shilpa et al. | 2019 | Ni-Cr alloy, Co-Cr alloy, Zirconia | Conventional firing | Shear Bond Strength test using universal testing machine | 45 specimens | Mean SBS values: Ni-Cr ≈ 35.55 MPa, Co-Cr ≈ 36.87 MPa, Zirconia ≈ 31.10 MPa | Metal-ceramic systems demonstrated higher bond strength compared to zirconia-ceramic systems |
| 21 | Hadi et al. | 2016 | Ni-Cr alloy | Conventional porcelain firing | Metal-ceramic bond strength evaluated using three-point bending test based on ISO 9693 | 30 specimens | No significant differences in bond strength among groups with different opaque porcelain thickness (0.1–0.3 mm) | Opaque porcelain thickness within the tested range does not significantly influence metal-ceramic bond strength |

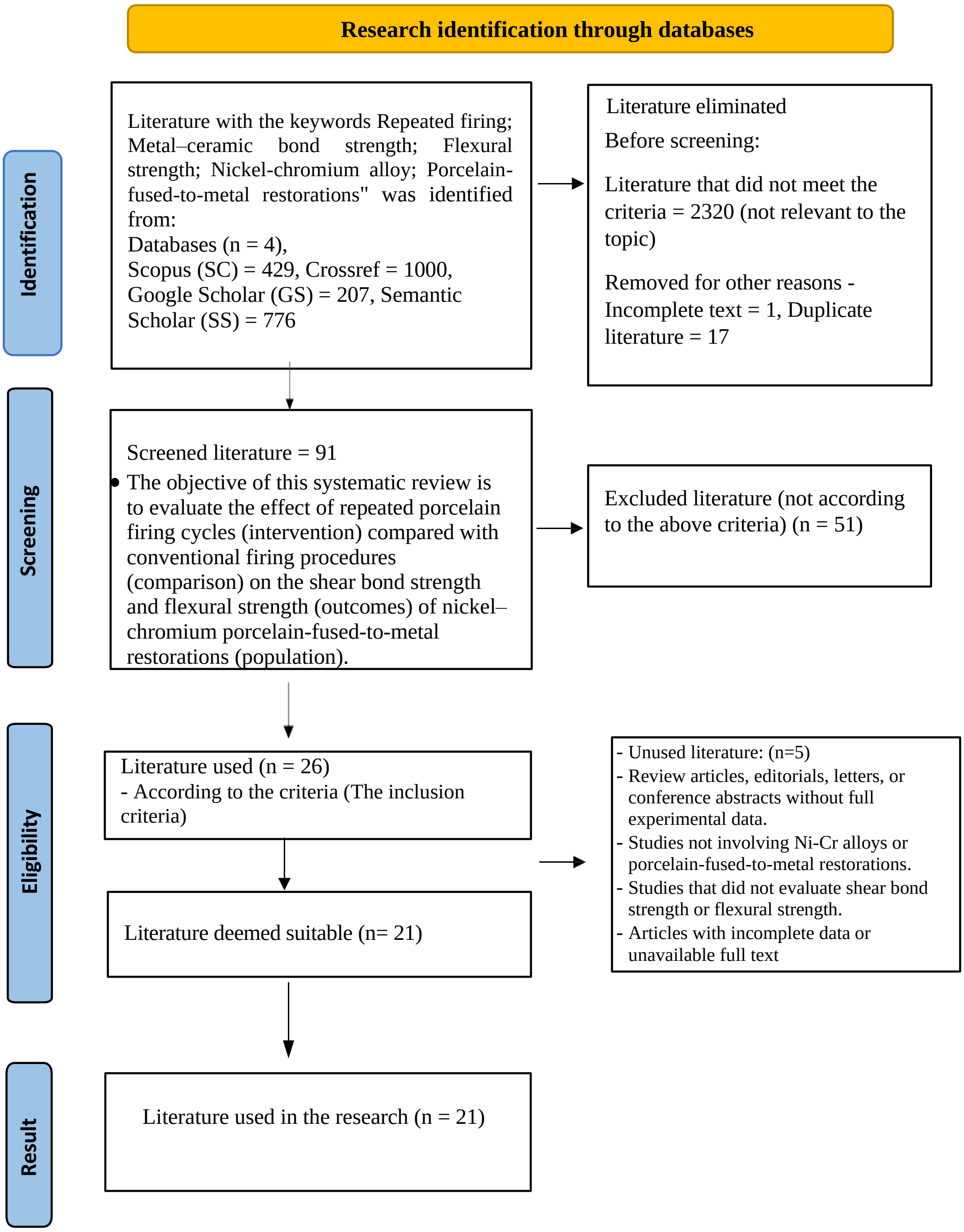


**Figure 1.** PRISMA Search process diagram (PRISMAStatement, 2020)

## DISCUSSION

1. Effect of Repeated Firing on Shear Bond Strength and Flexural Strength of Nickel-Chromium Fused-to-Metal Porcelain Restorations
   a. Effect of Repeated Firing Cycles

Repeated porcelain firing cycles are commonly performed during the fabrication and manufacture of porcelain fused-to-metal restorations. Several studies have examined the effect of repeated firing on bond strength between porcelain and metal alloys. The results show inconsistent findings depending on the number of firing cycles and experimental conditions. Farzin, Giti and Asalforush-Rezaiye, (2018) reported that repeated porcelain firing cycles of 3, 5, and 7 firings did not significantly affect the shear bond strength of metal-ceramic restorations. Similarly, Nair, Hegde and Vallabhaneni, (2016) found that multiple firing cycles did not significantly affect the bond strength of Ni-Cr and Co-Cr alloys, indicating that the metal-ceramic interaction remains stable under repeated thermal exposure. Conversely, other studies have reported that repeated firing cycles can lead to a gradual decrease in bond strength. Albarudi and Alsalameh, (2020) showed that shear bond strength decreased from 56.9 MPa to 43.54 MPa when the number of firing cycles increased from three to seven. This finding suggests that repeated thermal exposure can alter the formation of the oxide layer at the metal-ceramic interface and, consequently, reduce bond strength.

Previous research suggests that limited repeated firing cycles within the normal clinical range generally do not significantly affect bond strength, although excessive firing cycles can lead to decreased bond performance.

b. Effect of Alloy Composition (Ni-Cr)

Nickel-chromium is the most commonly used base metal alloy in porcelain-fused-to-metal restorations due to its high modulus of elasticity, corrosion resistance, and relatively low cost. Several studies included in this review investigated the bonding performance of Ni-Cr alloys. Studies by Abrisham *et al.*, (2017) and Shilpa *et al.*, (2019) showed that Ni-Cr alloys exhibit clinically acceptable shear bond strengths when bonded to dental porcelain. Similarly, Kamath *et al.*, (2022) reported that Ni-Cr alloys exhibited shear bond strengths ranging from 47.1 MPa to 65.6 MPa, depending on the applied surface treatment. Other studies of Ni-Cr alloys incorporating other restorative materials also confirmed the favorable bonding performance of Ni-Cr alloys. Bahri *et al.*, (2020) reported that Ni-Cr alloys exhibited shear bond strengths comparable to Co-Cr alloys and zirconia-based materials. Overall, these findings indicate that Ni-Cr alloys provide reliable bonds with porcelain veneers and remain suitable for metal-ceramic restorations.

c. Effect of Surface Treatment

The effect of surface treatment on metal frameworks is an important factor influencing metal-ceramic bond strength. Several studies, including this observation, have shown that proper surface preparation significantly improves adhesion between porcelain and metal alloys. According to a study by Kamath *et al.*, (2022), airborne abrasion using alumina particles significantly increased shear bond strength. Similarly, Alwahab, (2022) found that a combination of sandblasting and acid etching produced the highest bond strength (26.11 ± 1.85 MPa) compared to other surface treatments. A study by Jabbari *et al.*, (2016) also showed that the application of a metal primer and a tribochemical coating system significantly increased bond strength. These findings suggest that surface roughening improves micromechanical retention and promotes the formation of a stable oxide layer that contributes to the chemical bond between porcelain and metal.

d. Influence of Manufacturing Technique

Other influences, such as the fabrication technique used to produce the metal framework, can also affect the mechanical properties and bonding performance of metal-ceramic systems. Jhansi *et al.*, (2019) compared cast alloys with laser-sintered alloys and reported that the latter exhibited higher shear bond strength values than conventional cast alloys. Similarly, Mohammadi *et al.*,(2019) demonstrated that sintered alloys milled using CAD/CAM exhibited superior bond strength compared to conventional casting techniques. These findings suggest that modern digital manufacturing methods such as CAD/CAM milling and high-frequency laser melting can improve alloy microstructural uniformity and enhance bonding performance.

e. Flexural Bond Strength According to ISO 9693

The international standard ISO 9693 for assessing metal-ceramic bond strength typically uses a three-point flexural test. Several studies reviewed this study evaluated bond strength using the ISO 9693 method. Jhansi *et al.*, (2019) reported that bond strength values for Ni-Cr alloys made from virgin and recycled alloys remained above the ISO minimum requirement of 25 MPa, although recycled alloys showed slightly lower values. Similarly, Mohammadi *et al.*, (2021) reported bond strength values ranging from 20.98 MPa to 24.58 MPa depending on the alloy type and fabrication method. Despite slight variations, most metal-ceramic systems included in the reviewed studies demonstrated bond strength values close to or above the ISO minimum requirement. These findings indicate that Ni-Cr porcelain-fused-to-metal restorations generally meet the mechanical performance standards required for clinical applications.

f. Shear Bond Strength

Shear bond strength (SBS) was the most commonly used test method in the included studies to assess the restoration performance of metal-ceramic bonds. Reported SBS values vary widely depending on the alloy type, firing cycle, and experimental conditions. For example, Chanu *et al.*, (2025) reported the highest bond strength value for a fresh Ni-Cr alloy (64.65 MPa), while repeated recasting reduced the bond strength to 46.3 MPa. Similarly, Sreekala *et al.*, (2015) reported shear bond strength values of approximately 39.51 MPa before aging and 37.20 MPa after aging. Other studies reported shear bond strength values ranging from approximately 20 MPa to 35 MPa Patil and Shetty, (2018); Bahri *et al.*, (2020). Despite this variation, most studies reported shear bond strength values that remained within the clinically acceptable range for metal-ceramic restorations.

Overall, the findings from this systematic review indicate that repeated porcelain firing cycles can affect the shear bond strength and bond strength of Ni-Cr porcelain-fused-to-metal restorations. However, the magnitude of this effect depends on several factors, including the number of firing cycles, alloy composition, surface treatment, and fabrication technique. Most studies reported that bond strength values remained above the minimum requirements specified by ISO 9693, indicating that Ni-Cr PFM restorations remain mechanically reliable despite repeated firing procedures. However, excessive firing cycles and repeated recasting can reduce bond strength and should therefore be minimized during laboratory fabrication procedures.

## CONCLUSION

This systematic literature review investigates the effect of repeated firing on the shear bond strength and bond strength of nickel-chromium-fused-to-metal porcelain restorations. Based on the included synthesis studies, repeated porcelain firing cycles generally exhibit minimal influence on metal-ceramic bond strength when performed within conventional clinical ranges. However, excessive firing cycles and repeated recasting procedures can lead to a gradual decrease in bond strength due to changes in oxide layer formation and metal-ceramic interface characteristics. In addition, factors such as alloy composition, surface treatment, and manufacturing technique are identified as important determinants affecting bond performance. Most studies reported bond strength values that meet or exceed the minimum requirements specified by ISO 9693, indicating that nickel-chromium-fused-to-metal porcelain restorations remain mechanically reliable for clinical applications. Nevertheless, careful control of laboratory procedures is recommended to maintain optimal bond performance.

**Authors' Contribution**

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

**Avaialability of Data and Materials**

All data and supporting information are provided in the article.

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**Conflict of Interest**

The authors declared no conflict of interest, financial or otherwise.

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**Supplementary Material**

The PRISMA checklist is available as supplementary material on the publisher's website along with the published article. Supplementary material is available on the publisher's website along with the published article.

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