

Exploring the Influence of Recasting on Alloy Bond Strength – A Systematic Review and Meta-analysis

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Abstract

Purpose: This systematic review and meta-analysis was conducted to assess the importance of bond strength of re-casted base metal alloys used for dental restorations. **Materials and Methods:** This review follows the Preferred Reporting Items for Systematic Review and Meta-Analysis (2020) guidelines for systematic review and meta-analyses. An electronic literature search was performed through search engines such as (MEDLINE/PubMed), Cochrane Central Register of Controlled Trials, Science Direct databases using the MESH terminologies “Base metal alloy” “Nickel-chromium alloy” and “tensile strength.” The research question was formulated as – “What is the bond strength of re-casted base metal dental alloy as a restoration material as compared to the original casting?” using the Population, Intervention, Comparison, Outcome and Study framework. The risk of bias for quasi-randomized studies was assessed by methodological index for non-randomized studies tool. Total 121 articles were found eligible for screening after performing an extensive electronic literature search out of which 54 of them were found duplicates, 31 of them were eliminated using automated tools as they were not retrievable for appropriate data. Furthermore, 23 articles were screened for the assessment out of which 19 full-text articles were excluded for providing irrelevant data. After the screening four full-text articles met the eligibility criteria for the final assessment in this systematic review and meta-analyses. Recasting of base metal alloys with other metals has shown a reduction in the shear bond strength when compared with the original metal casting. **Result:** Ninety-two samples were assessed in each section. The bond strength of fresh alloy was found not significantly better with a mean difference of 1.12 (95% CI; -0.06; 2.31) at $P = 0.06$. **Conclusion:** Out of all the four studies evaluated, each study has shown a strong link between the bond strength of base metal alloys and the frequency of recasting procedure. Studies (2) and (31) suggests that an increase in the frequency and a change in the composition and percentage of the mixture of metal in the alloys during recasting procedure has shown a significant decline in the bond strength of the base metal alloys which have affected the durability and clinical performance of the dental restorations. Hence, this review suggests that further scope of research exists so as to find out the alternatives of recasted and recycled metals for dental restoration purpose.

Keywords: Base metal alloys, Bond strength, Modulus of elasticity, Nickel-chromium alloy, Recasting, biocompatibility.

INTRODUCTION

Dental restorations are essential for rebuilding the lost dental structure and meeting its cosmetic, functional, and form requirements. Superior physicochemical properties and also the biocompatibility of base metal alloys make them reliable restorations in dentistry. The key factor in ensuring the durability and lasting efficacy of the dental restoration is its bond strength. Any compromise in the bond strength can result in clinical failures affecting the overall integrity of the prosthesis. Metal-ceramic restorations in combination with the durability and strength of metal with the visually appealing aspect of porcelain have been proven extremely successful.^[1] Base metal dental casting alloys are the favored choice due to their low density, enhanced mechanical properties, affordability, and biocompatibility.^[2]

To achieve restoration with high clinical performance, a strong and successful bond between the metal and ceramic is the primary requisite. A chemical bond is created, when porcelain wets the surface of the metal, a thin adherent oxide layer is formed on the metal surface and the metal oxide form surface irregularities.^[3] For a powerful chemical link to form between the two structures, a stable oxide layer formation is a pre-

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requisite.^[4] To assess the strength of the binding between alloy and dental ceramic, the shear bond strength test is frequently employed.^[5,6]

This systematic review was conducted to assess the techniques employed, types of alloys, and the effects noted on the bond strength of the alloys after the recasting process so as to understand the importance of recasting and its effect on the bond strength of base metal alloys.

MATERIALS AND METHODS

In the present systematic review and meta-analysis, the current systematic review and meta-analysis utilize the suggestions from the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) Statement Checklist for formulating the research question through Population, Intervention, Comparison, Outcome, and Time format.^[7] The emphasis will be on the evaluation of bond strength of recasted base metal alloys and fresh base metal alloys in the blueprint planning of the study, further as per the grading of recommendations, assessment, development, and evolution guidelines, the quality of evidence was rated.

Through the systematic review and quantitative analysis of available data, this study seeks to address the following research question: “What is the bond strength of recasted alloy as a restorative material compared to the fresh casting in dental applications?”

Protocol and registration

The PRISMA (2020)^[7] criteria were followed to execute this systematic review and meta-analyses.

The review is registered under with the

Search criteria

An electronic literature search was conducted using search engines such as MEDLINE/PubMed, Ovid, Scopus, and Journal databases. The gray literature including conference papers, case reports, and dissertations were excluded completely.

Focus Question of the study:

“What is the bond strength of recasted base metal alloys as a restoration material as compared to the fresh casting in dental applications?”

Inclusion criteria

The following criteria were included in the study:

1. Full-text of articles published in English language only
2. *In vitro* non-randomized control trial studies that compared freshly cast alloys to alloys that have been recasted to evaluate bond strength (50%)

Exclusion criteria

The following criteria were excluded from the study:

1. *In vivo* studies
2. Articles published in language other than English.

3. Animal experiments
4. Research focused only on one population (either fresh or recasted alloy).

Data collection and extraction

According to the predetermined eligibility criteria, two reviewers have independently verified the studies for title, abstract, and final full-text.

Individual *in vitro* or *in vivo* interventions on fresh base metal alloys or individually recycled alloys were excluded from the criteria of selection. Animal experiments or those evaluating the bond strengths of high-tech and advanced machine-made dental prostheses were also not included in the study.

RESULTS

Study selection

Figure 1 shows that a total of 121 articles were found eligible for screening after performing an extensive electronic literature search out of which 54 of them were found duplicates, 31 of them were eliminated using automated tools as they were in retrievable for appropriate data. Furthermore, 23 articles were screened for the assessment out of which 19 full-text articles were excluded for providing irrelevant data. After the screening four full-text articles met the eligibility criteria for the final assessment in this systematic review and meta-analyses.

Study characteristics

The data extraction comprises a characteristic table which includes study ID, study design, study group, outcome group, outcome, and inference.

Main findings of the systematic review

After evaluating all the four studies included, two studies (2) and (6) have shown a significant decrease in the bond strength as the number of recasting during the procedure increases, whereas two studies (7) and (8) have shown that the addition of more than 50% of recast alloys has a significant declining effect over the bond strength of the metal-ceramic used in the dental restoration.

Meta-analytic results

On individual appraisal of each study outcome measure, recasting the base metal alloy exhibited a decrease in bond strength in all four studies, in comparison to the fresh casted base metal alloys. As the literature was uncommon and a wide diversity of recasting compositions was noted, the current analysis used a comparison of exclusive 50% re-casted alloys against the fresh base metal alloy. The data characteristic of each study is presented in Table 1 with a description along with the concordance of outcome measuring parameters such as shear bond strength.

Ninety-two samples were assessed in each section. The bond strength of the fresh base metal alloy was better but not statistically significantly, with a mean difference of 1.12 (95% CI: -0.06–2.31) at $P = 0.06$, as shown in Figure 2.

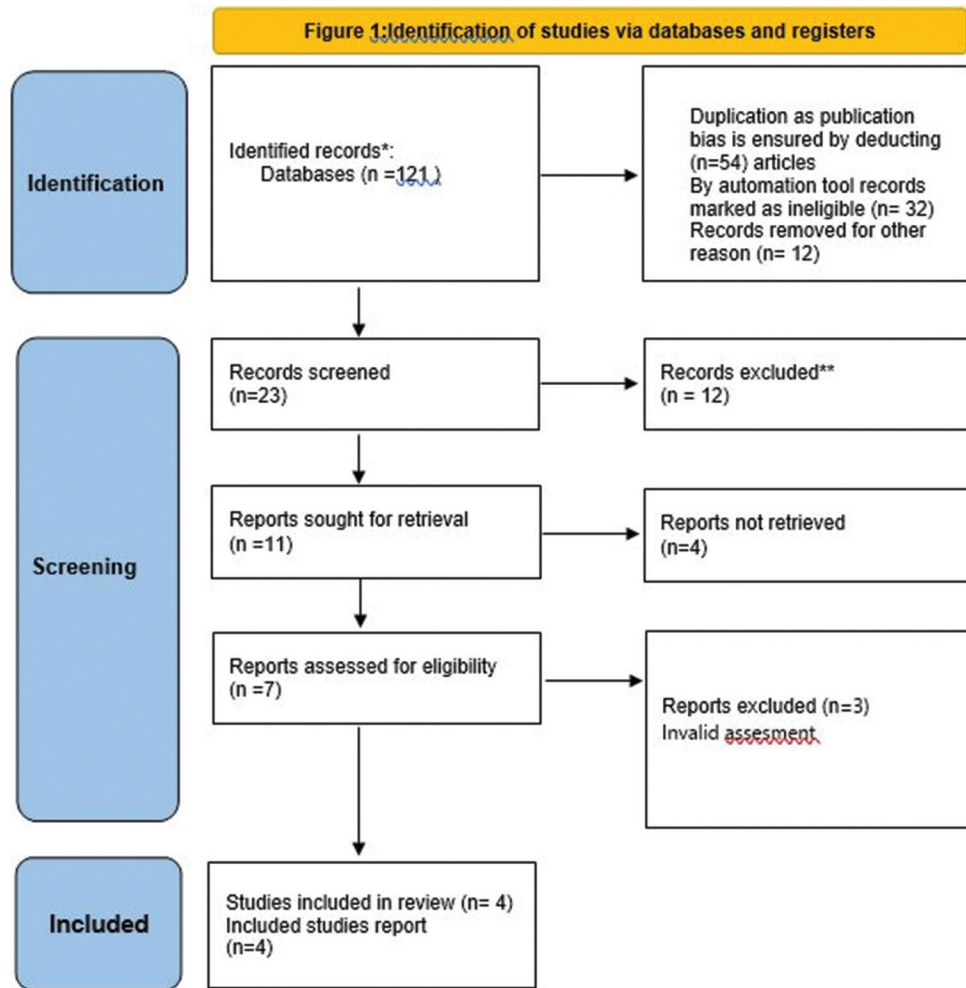


Figure 1: Depicting PRISMA (2020) flowchart for the identification and screening of the articles

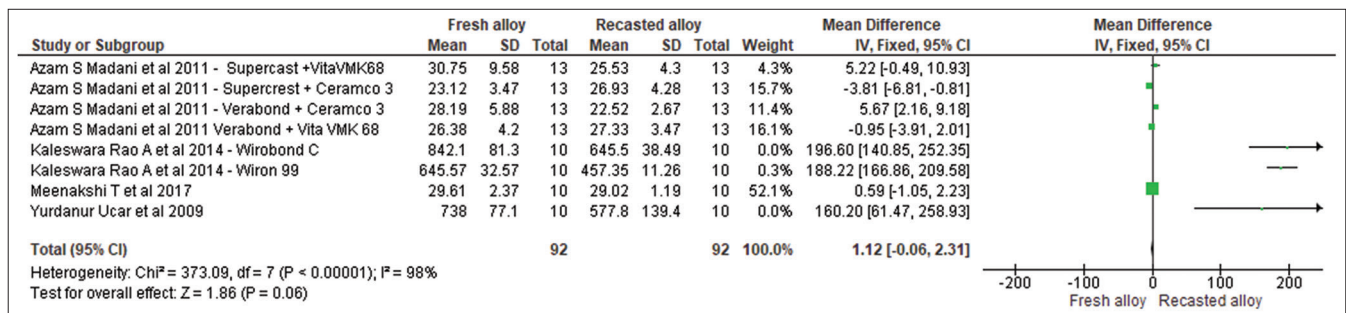


Figure 2: The forest plot showing the comparison between the bond strength of fresh metal alloys and recasted alloys

Statistical heterogeneity was assessed using the I² test, which is 98% in the present analysis, indicating higher heterogeneity, and hence, a fixed effect model was run. Publication bias was not assessed considering the limited literature available.

Due to the heterogeneity of this study, all statistical results were displayed on a forest plot using standardized mean differences with an attached effect model. The I²-value was used to assess the heterogeneity of various trials. Review Manager 5.4 software compared the bond strength between two groups: one with fresh alloys as base metal alloys for dental prostheses and the other with

50% reusable, recycled, re-casted alloys for the same use in dental prosthesis fabrication. The mean difference with a 95% confidence interval was calculated, and $P < 0.05$ was considered significant.

Assessment of the risk of bias of studies included

By means of methodological index for non-randomized studies (MINORS) tool, two authors independently carried out the risk of bias assessment for the studies included in this systematic review and meta-analysis.^[11] The risk of bias was evaluated for eleven domains, which include: (1) A well-defined objective (2) a digital technique for determining bond strength; (3) sample

Table 1: Data characteristic of each study presenting the bond strength of recasted base metal alloy

Study ID	Study design	Study group	Outcome parameters	Intervention	Results	Inference
Meenakshi <i>et al.</i> ^[8]	<i>In vitro</i>	A0-0%, once-cast alloy A1: 50% once-cast alloy		Ceramic application over re-casted alloys	The mean bond strength of group A0 was significantly higher than that of Group A1	Adding more than 50% of the recast alloy significantly decreased the bond strength of the metal ceramic
Atluri <i>et al.</i> ^[9]	<i>In vitro</i>		The bond strength of Ni-Cr and Co-Cr alloys with dental ceramic on repeated castings using SB test using a custom-made apparatus	Ceramic application over re-casted alloys	Metal-ceramic bond strength for Ni-Cr (842.10N) and Co-Cr alloys (645.57N) was calculated. Ni-Cr was reduced to 645.50N after first casting, and Co-Cr was reduced to 457.35N after first casting.	A decrease in bond was observed as the number of recasting's increased. A significant reduction in the bond strength was observed with the addition of the recast alloy. The addition of previously used base metal dental alloys for fabricating metal ceramic restorations is not recommended.
Madani <i>et al.</i> (2011) ^[10]	<i>In vitro</i>	Group A: 0%, once-cast alloy Group B: 50% once-cast alloy	Bond strength of recast base metal alloys at different percentages	Ceramic application over re-casted alloys	An adequate bond occurred when the fracture stress was above 25 MPa, so the bond strengths in all groups were compared to 25 MPa by a t-test. The bond strengths of Group A were significantly higher than those of Group B.	Adding more than 50% of the recast alloy significantly decreased the bond strength of the metal ceramic.
Ucar <i>et al.</i> ^[2]	<i>In vitro</i>	C0 Cast from 100% fresh alloy C1 Cast from 50% fresh alloy and 50% remnants from the first group	The shear bond strength (SB) load between the recast alloy and dental porcelain was evaluated using UTM	Ceramic application over re-casted alloys	Mean SB load C0-738.0±77.1 N C1-577.8±139.4 N mean peak load C0-39.8±1.79 N mean peak load of the specimens in the other groups	A decrease in bond was observed as the number of recasting increased.

Table 2: The methodological quality of all the studies included

Checklist	Madani <i>et al.</i> ^[10]	Nandish <i>et al.</i> ^[22]	Meenakshi <i>et al.</i> ^[8]	Ucar <i>et al.</i> ^[2]
Clearly stated aim	2	2	2	2
Digital method of measuring cytotoxicity	2	2	2	2
Validation of sample size	0	2	1	1
Sample randomization	2	2	1	1
Description of fabrication of recasted alloy	2	2	2	2
Test group material	2	2	2	2
Measurement of standardization	2	2	2	2
Measurement method	2	2	2	2
Measurement reproducibility	2	2	2	2
Adequate statistical analysis	2	2	2	2
Overall Appraisal	Include	Include	Include	Include

#0: Not reported; 1: Inadequately reported; 2: Adequately reported

size validation; (4) sample randomization; (5) a description of the re-casted alloy's manufacturing; (6) material for the test group; (7) standardization measurement; (8) method of measurement; (9) reproducibility of measurements; (10) sufficient statistical analysis; and (11) comprehensive evaluation.

The MINORS was used for the methodological assessment of the excellence of the included studies. The scale is made of 10 items, with a score of 0 for not reporting any item, 1 for inadequate reporting, and 2 for adequate reporting. The

maximum probable score for each study will be 20. Based on each item appraised, a conclusion is made (presented in Table 2) for the inclusion of the study.

The excellence of the included studies for the present analysis was decent, thus reducing the probable risk of bias.

DISCUSSION

The analysis conclusion points to a noteworthy trend: freshly casted alloy performs better in terms of bond strength than

re-casted base metal alloy. This review's main contribution is to the meta-analysis's extraction or summary of data from synthesized and published quasi-randomized *in vitro* trials assessing the bond strength of recast alloy against fresh base metal alloy, where fresh base metal alloy's strength and quality are significantly higher. The further analysis demonstrates that the primary reason for the base metal alloy's decreased metal-ceramic bond strength is the increased thickness of the oxide layer. The planar shear test and the flexural test were used to determine the bond strength of porcelain to a base metal alloy. When applying parallel or perpendicular forces, the empirical data on the recycled re-casted bond metal alloy demonstrate in the context of fresh alloy and recycled metal, fresh alloy has better bond integrity at the interface. Factors such as alloy degradation, microstructural changes, and surface oxidation can contribute to the observed reduction in bond strength in re-casted metal.^[12] The porcelain bond strength with recasted base metals has been reported in the literature that the porcelain's bond to the base metal alloy weakens after the initial recasting of the alloy. There are no appreciable differences between the first and second re-castings.^[10]

Four studies were analyzed in this systematic review to assess the reliability of recasting of base metal alloys over the shear bond strength of the. In one of the study, Atluri *et al.*^[9] found that for both Ni-Cr (664.63N) and Co-Cr alloy (497.41N), the addition of re-casted alloy to the fresh alloy significantly reduced the metal-ceramic bond strength. This decrease in bond strength can be attributed to the increased frequency of interfacial voids that arise with an increase in the fraction of recast metal.^[13-15] The failure of the recast alloy may also be related to the compositional change that occurs after subsequent castings. According to Tucillo *et al.*^[16] successive castings may cause the adhering oxide layer created at the metal surface to thin off, which would weaken the binding.

According to researchers, the shear bond test is the most reliable method for determining how well two materials are bonded. In the three-point bending (3PB) test, tensile stress prevails, whereas shear stress does so in the shear bond (SB) test.^[17,18] As stated by Madani *et al.*,^[10] adding more than 50% of the recasted alloy causes a notable decrease in bond strength, and recasting the base metal alloy also causes a decrease in bond strength. A strong bond between the porcelain layer and the cast alloy is necessary for the metal-ceramic restoration to last^[19] that studies have shown that the main reason for the decreased metal-ceramic bond strength is the increased thickness of the oxide layer. One explanation put forth is that in these alloys', Berrillium, Aluminium, and Yttrium contents might decrease during the remelting process^[20] Juliano C done a research on how recasting affects bond strength, and found that the alloy's surface has less AlNi₃ than it had before. It is possible that the recasting of base metal alloys would result in a decrease in both the amount of Be and the amount of Al on the surface.^[21] It gives the impression that when the quantity of recast alloy is >50%, it has a negative impact on the strength of the metal-ceramic bond.

Ucar *et al.*^[2] concluded in their study that the compositional stability of an alloy may be impacted by recurring castings of the same alloy. Minor and trace elements, including silicon, iron, tin, gallium, and zirconium, as well as aluminum, beryllium, boron, carbon, cobalt, copper, and silicon, are thought to change after multiple castings. Bond strength is reduced as a result of these elements' effects on the chemical bond. The results were not unexpected because it has been noted in the literature that repeatedly casting the same alloy may affect its capacity to maintain its composition. After multiple castings, changes are anticipated in trace and minor elements (Al, Be, C, Si, Fe, and Sn). Because these elements affect the chemical bond, the bond between metal and ceramic is weakened as a result.^[22]

Nandish *et al.*^[23] stated that a weakened bond has potential to cause bond failure and porcelain fracture inside the prosthesis.

Pahwa *et al.*^[24] it can be inferred that the bond strength value significantly decreases with an increase in amount of recast metal in the given sample, results in weaker metal-ceramic bond strength. Kumari *et al.*^[25] suggested that recasting causes reduction in metal-ceramic bond strength since recasting should be avoided.

The meta-analysis primarily focuses on the reliability of bond strength of the base metal alloys after recasting. Other variables such as biocompatibility, wear resistance, durability, and clinical performance are not thoroughly explored. Manufacturers and researchers can focus on improving the recasting process, alloy composition, and surface treatments to mitigate the negative impact on bond strength.

CONCLUSION

The outcomes of shear bond strength in terms of planar and flexural tests provide a comprehensive understanding of the bond strength difference. The reduced bond strength in recasted metal implies a higher risk of clinical failure, including debonding, fractures, or compromised longevity of the dental prosthesis, directly compromising its long-term success and durability. The bond strength was consistent in mechanical properties in fresh base metal alloys but decreased as the recasting of 50% metal was used or the recycling of metal was done. Within the limitations of the intervention studies, the conclusion from robust synthesis determines that fresh alloys have more bond strength than 50% recasted alloys. For dental prostheses' fabrication, it is not advisable to include recasted base metal alloys because this reduces the properties of the alloy in terms of strength, durability, and integrity.

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