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Research Article

Evaluation Of Flexural Strength Of Indirect Composite And Cobalt Chromium Metal With And Without Aging

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ABSTRACT

Aim and Objective: The study aimed to assess the flexural strength (σf) of Cobalt Chromium compared to indirect composites with and without aging. It sought to confirm the hypothesis that Cobalt Chromium (Co-Cr) metal exhibits a higher σf value than indirect composites and that these characteristics are positively linked. Five bar-shaped samples (25 mm x 2 mm x 2 mm) were created for both the metal and indirect composite materials following specific guidelines. These samples underwent a three-point bending test using an INSTRON 9400 universal testing machine at a crosshead speed of 0.5 mm/min as per ISO4049 standards. Results indicated that the metal specimens showed higher average σf values compared to the indirect composites. Furthermore, the mean values of these properties demonstrated a positive correlation (r = 0.91), confirming the initial hypotheses of the study.

Material and Methods:

Cobalt-Chromium: Metallic frameworks (25 x 3 x 0.5 mm(3); ISO 9693) (N = 60) were 3-D printed using direct metal laser sintering(DMLS) in Co-Cr and airborne-particle abraded (Al(2)O(3): 150 mum) at the central area of the frameworks (8 x 3 mm(2))

Indirect composite : 5 bar-shaped specimens were fabricated from an indirect composite system, following the manufacturer's instructions and the ISO 4049 specification. The composite resin was packed inside a stainless steel mold positioned on a glass slab to obtain the required dimensions (25 x 3 x 0.5 mm). A thin glass slab was positioned on the mold containing the material, which was light-cured.

Results: Flexural strength was tested using the Universal Testing Machine before and after the aging cycle. After initial flexural strength measurement, the remaining specimens were stored in water or subjected to thermocycling for 1, 7, 28, and 90 days,(water stored: n=5 and thermocycling: n=5) were tested. After the flexural strength test, failure types were noted. The data were analyzed using Tukey's test (α= 0.05)

Conclusion: The study noted that the initial flexural strength of Cobalt Chromium (Co-Cr) and the indirect composite materials were similar. However, the aging process had distinct effects on these materials. In the case of Co-Cr, there wasn't a notable variance in its flexural strength after the aging period. Conversely, the indirect composite material displayed a significant decrease in flexural strength specifically after 90 days of aging. This divergence in behavior post-aging suggests that while Co-Cr maintained its strength consistency, the indirect composite material experienced a noteworthy reduction in its mechanical integrity over time, particularly after the 90-day mark.

Introduction

The rising expenses associated with noble metal alloys have prompted a shift toward the utilization of base metal alloys in constructing frameworks for fixed and unitary partial prostheses. Among these base metals, nickel-chromium and cobalt-chromium (Co-Cr) alloys are the most prevalent.(Mengucci et al., 2016) However, nickel-chromium alloys containing beryllium may pose toxicity concerns linked to beryllium exposure, as well as potential allergenic reactions due to nickel content. Consequently, there has been a growing preference for Co-Cr alloys due to their compatibility and reduced likelihood of adverse reactions. Additionally, these non-precious alloys exhibit exceptional mechanical properties, including resistance to permanent deformation and a high modulus of elasticity. These characteristics afford these alloys an advantage in creating thin yet sturdy frameworks essential for partial fixed prostheses.(Mirković, 2007)
Composite resin veneered crowns have emerged as a viable alternative to metal-ceramic restorations due to their simplified manufacturing process and cost-effectiveness. However, challenges associated with composites, such as fluid leakage at the metal-resin junction, discoloration, limited wear resistance, and weak bond strength, have led to the development of various composite resin-metal bonding systems. (Kountouras et al., 1999)These systems aim to enhance the bonding capability of composite resin veneers to metal, enabling their application in anterior and posterior restorations akin to metal-ceramic restorations.(Ilie & Hickel, 2011)
To address these challenges, these bonding systems often incorporate multiple strategies. They may involve surface preparation methods like heating, tin plating, ion coating, and seal coating to optimize the metal surface. Micro-mechanical retention techniques such as sandblasting or chemical/electrolytic etching create a surface conducive to bonding.(Dolfini Alexandrino et al., 2023) Additionally, strategies like incorporating metal beads, and mesh, or employing pitted metal aim to enhance micro-mechanical retention. Chemical bonding via primers, particularly silane coupling agents, facilitates strong adhesion between the metal and resin components. Furthermore, the use of opaque resins is employed to foster adhesion and streamline the bonding process.(de Vasconcellos et al., 2010) These multifaceted approaches collectively work towards improving the adhesion and longevity of composite resin veneers on metal substrates, making them suitable for various dental restorations in both anterior and posterior regions similar to traditional metal-ceramic restorations.(Hong et al., 2020)
The objective of this study was to evaluate the flexural strength (σf) and hardness (H) of cobalt-chromium metal and indirect composites, testing the hypothesis that cobalt-chromium produces higher flexural strength and hardness values than indirect composite and that these properties are positively related.

Material and Methods

Fabrication of metallic framework

A rectangular acrylic template (27 × 3 × 0.5 mm) was used for the fabrication of the frameworks. These were then scanned using the 3-shape Trios scanner. Digitally modified to achieve the precise dimensions. (Fig 1)
The generated output STL file was then used to print the design in cobalt-chromium using the "*EOS DMLS M 100 (Direct Metal Laser Sintering)*"

Fig 1. STL design of Sample

After fabrication, the margins of the frameworks were trimmed to the final dimensions of 25 × 3 × 0.5 mm, with the measurements controlled using a digital paquimeter with a precision of 0.01 mm. (Fig 2)

Fig 2. Prepared Co-Cr Samples

After the laser sintering processes were completed, all the laser-sintered metal frameworks were annealed in a sintering furnace (Mos-B/160; Protherm) for 4 hours between 450 C and 750 C according to manufacturer instructions, removed from their supports, and abraded with 250-mm Al_2O_3 particles from a 10-distance at a pressure of 250 kPa .

Fabrication of the indirect composite framework

5 bar-shaped specimens were fabricated from an indirect composite system, following the manufacturer's instructions and the ISO 4049 specification. The composite resin was packed inside a stainless steel mold positioned on a glass slab to obtain the required dimensions (25 x 3 x 0.5 mm). A thin glass slab was positioned on the mold containing the material, which was light-cured.

After fabrication, the margins of the frameworks were trimmed to the final dimensions of 25 × 3 × 0.5 mm, with the measurements controlled using a digital paquimeter with a precision of 0.01 mm. (Fig. 3)

Fig 3. Indirect Composite Samples

The upper and lower surfaces of the specimens were light cured intensity 400 mW/cm2) for 40 s per unit output diameter. The Polymerization procedure of the indirect composite systems followed the manufacturer's instructions.ISin was first light-cured with a halogen lamp with an intensity of 400 mW/cm2 (Visio Alfa unit, 3M-ESPE)for 15 s, and finally cured under light and vacuum(Visio Beta Vario unit, 3M-ESPE) for 15 min. The specimens were first light-cured following the direct composite procedure and finally cured in 2 cycles of 4 min using a polymerization box (EDG-LUX, EDG Equipamentos) containing four blue-light bulbs and a rotating tray, according to the manufacturer's instructions.

Flexural Strength Calculation

The flexural tests were performed in a universal testing machine (Instron 4301, Instron Corp., Norwood, MA), (Fig 4) with the load applied at a constant speed of 1.5 mm/min until fracture. The load that led to the initial separation of materials was obtained in KGF and converted to N, utilizing the following equation:
Psi= 3PI/2 wh2N/mm2

Fig 4. Flexural strength using Universal Testing Machine

Aging process

The procedure involved immersing all specimens in 37°C water for 15 minutes and then polishing them using 600 to 1,200 grit SiC paper to eliminate any excess material, following ISO 4049 specifications. To ensure accuracy, the dimensions of the specimens were confirmed using a digital caliper. Afterward, these specimens were stored in distilled water at 37ºC for 24 hours. Following the storage period, the specimens underwent a three-point bending test using a universal testing machine. The test was conducted at a crosshead speed of 0.5 mm/min until the specimens fractured. (Fig 5).Subsequently, the Flexural strength values (σf) were calculated in megapascals (MPa) based on the results of the test.(Diken Turksayar et al., 2022)

Fig 5. Aging process

Statistical analysis

The average values of each group were assessed through a 2-way ANOVA, employing the flexural strength test as the dependent variable. The independent factors considered in the analysis were the combinations of indirect composite and Co-Cr metal, along with the different fatigue conditions. Significance was determined using p-values, where any value below 0.05 was deemed statistically significant across all tests. To further explore differences between specific groups, multiple comparisons were conducted using Tukey's adjustment test, allowing for a comprehensive understanding of the variations observed in the data.

Results

Table II presents descriptive statistics detailing the flexural strength measurements for both types of aging concerning Co-Cr and composite resin, considering various aging levels. Specifically, when examining the flexural strength of samples following specific aging durations with water storage, no notable differences between the metal (Co-Cr) and indirect composite resins were evident after 1 day (P=.295) and 7 days (P=.085) of aging (Table II). However, after 28 days (P<.001), the highest flexural strength was observed for the indirect composite and Co-Cr. While Co-Cr exhibited relatively consistent performance, the indirect composite showed significantly lower values at this point. Subsequently, after 90 days, the flexural strength of the indirect composite notably decreased, presenting significantly lower values (P=.001) compared to Co-Cr.

Table II- The mean (± standard deviations) flexural strength values (N) for Co-cr and indirect composite with and without mechanical and thermal cycling conditions. (Tukey's test, α = 0.05)

Experimental Groups	Before Aging	After Aging	Mean SD
Cobalt-Chromium	19.8 ± 4.2	19 ± 6.7	19.41 ± 5.5
Indirect composite	18.25 ± 4.5	16.74 ± 3.1	17.6 ± 5

The results for long-term flexural strength stability for indirect composite resin in water storage showed the highest flexural strength after 1 day and 7 days of water storage (P<.001) . (Fig 6).

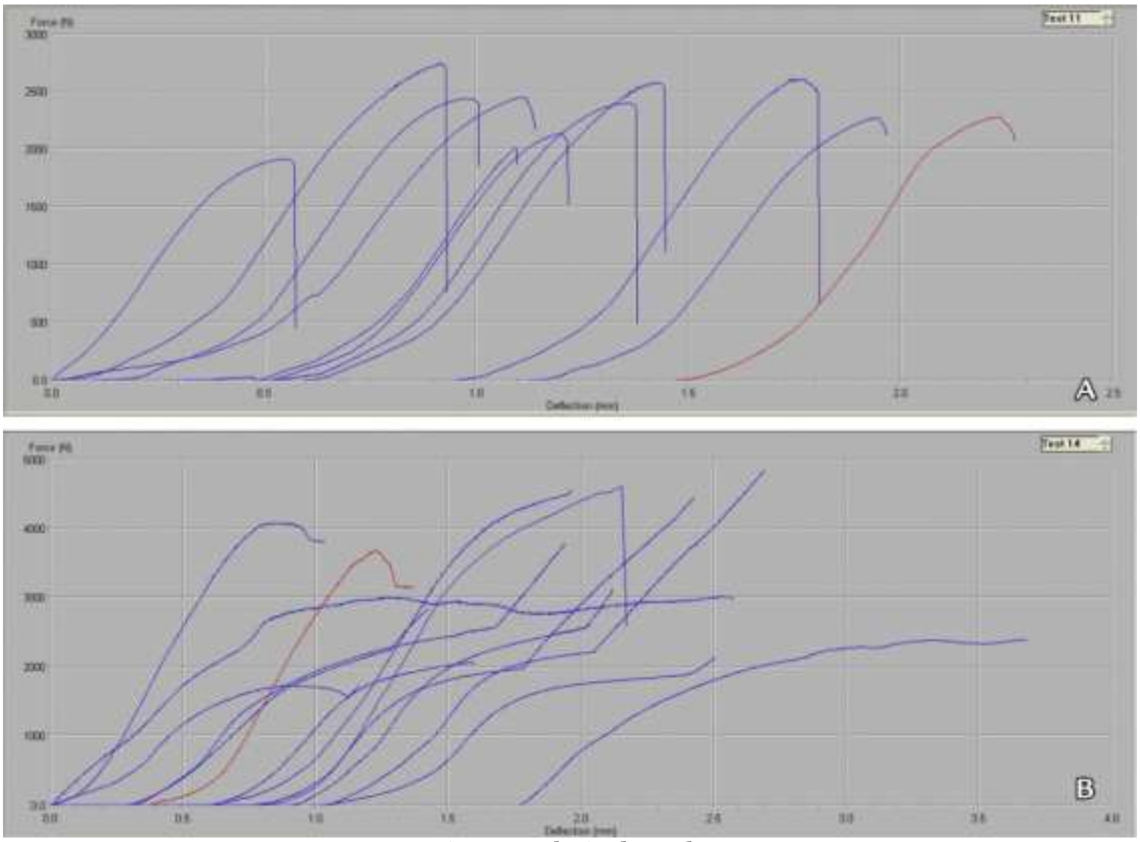

Fig 6. Analytical results

In the context of long-term flexural strength stability underwater storage, the findings indicated no notable difference for Co-Cr before and after the cycling procedure. Generally, the metal framework demonstrated superior stability in terms of flexural strength when subjected to prolonged exposure to flexing forces compared to the indirect composite. As the aging cycle progressed, the indirect composite exhibited reduced values, highlighting its decreased resistance to long-term flexural stress compared to the Co-Cr metal framework.

Discussion

The study revealed discernible differences in the properties of the tested samples before and after aging, leading to the acceptance of the null hypothesis. The indirect composite involved a post-polymerization process, a crucial factor influencing its composition and polymerization parameters, ultimately dictating the desired properties of the composite resin.(Papadiochou & Pissiotis, 2018) This particular composite resin necessitated an extended polymerization time, potentially enhancing its surface properties. Thus, not only the filler content but also the polymerization mode likely influenced both the mechanical and optical properties of the material.(Gresnigt et al., 2019)

Interestingly, the indirect composite exhibited the highest flexural strength following water storage and thermocycling compared to other tested veneering composite resins. However, it's noteworthy that the flexural strength of all veneering composite resins decreased after undergoing water storage and thermocycling—a trend observed in similar aging studies. In clinical settings, veneering composite resins endure complex mastication forces and considerable flexural stress.(Gresnigt et al., 2021) Hence, for restorations exposed to substantial masticatory stress, the desire for high and enduring flexural strength remains crucial to prevent fractures and ensure long-term stability.

The study found no notable variance in flexural strength among the laser-sintered specimens despite varying layer thicknesses, ultimately leading to the acceptance of the research hypothesis. However, a clear trend emerged: as the framework length increased, there was a noticeable decrease in flexural strength.(Diken Turksayar et al., 2022) This finding underscores the pivotal role of mechanical properties, particularly flexural strength, in determining the long-term clinical viability of metal-ceramic restorations. The significance of high flexural strength in metal frameworks cannot be overstated, as it directly impacts the overall success of metal-ceramic restorations. Insufficient bending resistance in the metal framework can result in fractures within the porcelain layer.(Hong et al., 2020) Therefore, ensuring that metal frameworks possess a high level of flexural strength is crucial to uphold the integrity and durability of these restorations over time.

In this study, the laser-sintered metal frameworks displayed significantly higher average flexural strength compared to the indirect composite resin. (Gustavsen et al., 1989)The mean flexural strength of the Co-Cr group exceeded that of the indirect composite group. Importantly, none of the test groups, particularly the laser-sintered groups, reported a mean flexural strength lower than 1000 MPa, indicating robust strength across these samples.
The observed difference in flexural strength between the two groups can be attributed to variations in microstructure.(Vásquez et al., 2009) The laser-sintered specimens exhibited a much finer microstructure, whereas the indirect composite specimens displayed a relatively coarse dendritic microstructure. Additionally, the presence of polymerization shrinkage defects notably reduced the flexural strength of the composite specimens. (Kaleli et al., 2022)This discrepancy in microstructural features and the impact of polymerization-related shrinkage defects likely contribute significantly to the observed differences in flexural str(Gresnigt et al., 2021)ength between the laser-sintered metal frameworks and the indirect composite resin.
Specimens produced through laser sintering exhibit an almost flawless microstructure, highlighting their high structural integrity.(Edelhoff & Sorensen, 2002) However, when examining the stress-strain curves, it becomes apparent that the cast specimens showcased greater ductility compared to their laser-sintered counterparts. This discrepancy suggests that indirect composite frameworks might present a challenge in terms of bending resistance.(Rodrigues Junior et al., 2007)
The cast specimens showed a tendency to deform plastically without fracturing. While this may seem beneficial, such plastically deformed but unfractured restorations can pose clinical issues. Specifically, they could lead to misfitting of the restoration margin, potentially increasing the risk of secondary caries and causing complications related to periodontal health. Given these findings, it's prudent to consider that laser sintering technologies might offer a more promising mechanical outlook compared to indirect composite polymerized restorations.(Niem et al., 2019) Particularly for long-span fixed partial dentures, where durability and resistance to deformation are critical, laser-sintered methods could potentially provide better long-term survival and reduce the risk of clinical complications associated with poorly fitting restorations.(Gresnigt et al., 2019)

Conclusion

The conclusions drawn from this in vitro study are as follows:
-Laser-sintered metal frameworks demonstrated superior flexural strength compared to indirect composite frameworks. This indicates that the metal frameworks produced through laser sintering exhibited higher resistance to bending forces than their counterparts made from indirect composite materials.
-The Co-Cr framework without aging showed the highest flexural strength values among the tested groups. However, it's important to note that while this difference was notable, it did not reach statistical significance. This suggests that while the Co-Cr framework without aging displayed the highest flexural strength values, the difference observed wasn't significant enough to conclusively state its superiority over other groups in a statistically significant manner.

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