Comparative analysis of weld strength of nickel-chromium and cobalt-chromium base metal alloys when submitted to tungsten inert gas welding

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ABSTRACT

Long span base metal alloy fixed prosthesis and partial dental prosthesis frameworks most often require welding for better fit and adaptation. The type of metal alloys used and its effect on the weld strength of the prosthesis have to be investigated. The aim of the study is to comparatively analyze the weld strength of nickel-chromium (Ni-Cr) and cobalt-chromium (Co-Cr) base metal alloys when subjected to tungsten inert gas (TIG) welding. 10 nickel- and cobalt-based specimens were obtained by casting of castable resin patterns of dimension 25 mm × 3 mm × 1 mm. Welding of the samples was carried out using the Lampert PuK 2 welding equipment, and a three-point bend test using a universal testing machine was carried out to evaluate the weld strength of the specimens. Statistical analysis was carried out using the SPSS software version 23. Higher weld strength was observed in the Co-Cr alloy (mean = 898 MPa) than in the Ni-Cr alloy (mean = 690 MPa), when submitted to TIG welding ($P < 0.05$). TIG welding could be a better alternative for joining base metal alloys for long span edentulous cases, and cobalt-based alloys could be better alternatives to nickel-based alloys that usually tend to cause hypersensitivity reactions.

Key words: Base metal alloys, cobalt-chromium alloy, innovation, innovative, laser welding, nickel-chromium alloy, tungsten inert gas welding, weld strength

INTRODUCTION

Metal and its alloys have been used in the fabrication of dental prostheses for a very long time now as they are inexpensive and biocompatible. Among the most commonly used base metal alloys, nickel-chromium (Ni-Cr) and cobalt-chromium (Co-Cr)–based materials are the most commonly used alloys due to their satisfactory clinical performance and good physical properties, especially in cases of long span edentulousness, where a brittle material-like zirconia cannot be used.[1-5] This has improved the quality of treatment for a huge number of patients, especially those looking for cheaper treatment alternatives.[6,7] Nickel-based alloys are the most widely used alloys for porcelain-fused-to-metal restorations. However, due to the potential health problems like contact dermatitis caused due to nickel, the Co-Cr alloys are now being researched as an alternative alloy material.[8]

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Achieving passive fit and good adaptation of extensive or long span cast framework is usually difficult due to shrinkage of metal postsolidification or an absence of parallelism between the components of the framework. This may lead to ultimate failures of fixed dental prosthesis in the long run.[9] In such conditions, welding of various components can help achieve better adaptation of the framework than that provided by one-piece metal structure. This procedure not only aims to reduce likelihood of failures while manufacturing but also improves the fit of prostheses to abutments.[10] Conventional brazing utilizes oxygen or air torch and includes joining of parent materials with other metals; this helps reduce corrosion resistance.[11-13] To overcome the disadvantages of conventional brazing, various methods such as welding using lasers and tungsten inert gas (TIG) welding were introduced.

Laser is a safe and low-cost process of welding and can be used with ease because the heat does not spread from the welded site and is restricted to a small area. It is beneficial as it dissipates heat in less time and causes minimal distortion, but it has often given varied strength values.

TIG welding is used when a different material is used around the area of interest.[14] It is important to note that this method is performed in an insulating atmosphere[13,15] because the environmental impurities can turn the metal crumbly, leading to alterations in the crystalline structure. This may alter properties of base metal alloys. As TIG welding equipment is cheaper than lasers, it reduces the overall cost of tooth tissue-supported rehabilitations with cast partial dentures or implant frameworks.

A study conducted previously[16,17] compared TIG welding with laser welding, where higher flexural strength was obtained when using TIG welding than Nd:yttrium-aluminum-garnet laser welding group because of superior heat source (TIG). The aim of the current study was to compare, using the mechanical strength testing, the weld strength of different base metal alloys (Ni-Cr and Co-Cr) when subjected to TIG welding as an inexpensive alternative for tooth- and tissue-supported full mouth rehabilitations. The null hypothesis states that there was no difference in the weld strength of Ni-Cr and Co-Cr base metal alloys when subjected to TIG welding. Our research and knowledge have resulted in high-quality publications from our team.[18-36]

MATERIALS AND METHODS

Preparation of specimens

This study was conducted in Saveetha Dental College, Chennai, India, after getting the ethical consent from the institutional review board with approval number IHEC/SDC/PROSTHO/21/169. The number of samples was calculated using a free software program G*Power 3.1.9.3 software for Mac OS X®; Department of Psychology; Olshausenstr, Kiel, Germany[37] using the results of a similar study. A sample size of 10 specimens in each group was obtained. These were designed using an open source computer aided design (CAD) software (Sketch up Pro, Trimble company, Sunnyvale, California, U.S) before three-dimensional (3D) printing. For assessing the weld strength, test bars (n = 10, for each material) (25 mm × 3 mm × 1 mm) were designed based on the International Standards Organization. The design was converted into standard tessellation language (STL) format. The STL was transferred to a CAD- computer aided manufacturing software for 3d prototyping (Formlab 3D printer, Formlabs®; Boston, Somerville, MA) of the specimens. Specimens were placed at a 90° orientation for accuracy.[38] 3D printing was done using castable resin (Nextdent cast, Vertex global holding, 3D systems, Netherlands), and postprinting, the specimens were subjected to casting. The methodology is depicted in Figure 1.

Casting of specimens obtained

The specimens were processed in a phosphate-bonded investment (Vesto-Fix, DFS) at a ratio described by the manufacturer and cast in Ni-based alloy (Niadur, DFS) and Co-based alloy (Biodur soft, DFS). The procedure was carried out using lost-wax technique using open flame centrifugal casting. Postcentrifugation followed by cooling of the metal, the samples were subjected to sandblasting to remove impurities and were finished using carbide tungsten drills.

Tungsten inert gas welding and weld strength

TIG welding was carried out using Lampert PuK 2 welding equipment and PUK Optic Device (Lampert Werktechnik, GMBH). Argon gas was released to ensure an oxygen-free environment. The settings were kept as 10 V, 15–20 A, and 12 s of working time. The specimens were then subjected to a flexural strength test in an UTM [Figures 2 and 3] machine (Instron Electropuls, Illinois Tool Works, Inc.®; Bangalore, India). A three-point bend test was performed using a load, with measuring speed of 0.5 mm/min, using force of 500 kg and a length of 20 mm (ISO 6872:2008). The amount of stress strain was obtained using Eq. (1) where l = length between supports, b = width and h = height of each sample, and σ = highest weld strength (MPa). A total of 10 samples per group were assessed. Data were analyzed statically using a software package.

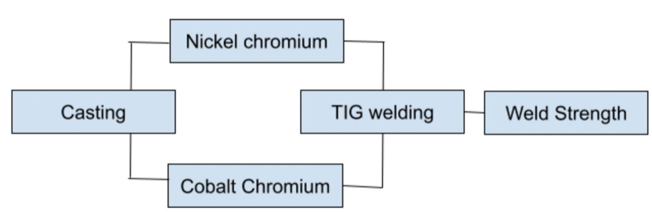

Figure 1: Flowchart of the procedure

$\sigma = 3fl/2bh^2$ = weld strength. (1)

Statistical analysis

Data were distributed and tabulated in Google sheets. The data were analyzed using IBM SPSS software (Version 23.0 Armonk, NY: IBM Corp.), and unpaired *t*-test was used to statistically assess the maximal weld strength. If $P < 0.05$, it was considered significant.

RESULTS

Mean weld strength for each group. The maximum mean values were observed for Ni-Cr alloys by TIG. The mean weld strength for Co-Cr alloy was 898.68 ± 23.83 MPa and for Ni-Cr alloys was 680.94 ± 36.87 MPa. There was a significant difference among both the groups ($P < 0.005$) [Figures 4 and 5].

DISCUSSION

The success of any full-mouth rehabilitation procedure is dependent on the use of the right materials and methodology. Achieving a good fit of prosthetic restorations is necessary, especially for long span or one-piece cast partial denture framework.[39] This can lead to failure of the prosthesis. In this situation, welding can help in better adaptation of these substructures.[40] Various methods for welding have been identified, such as simple gas torch welding to highly sensitive techniques such as lasers and TIG welding.[13,40] In previous studies conducted regarding the efficacy of these methods, TIG welding improved the flexural strength of the parent metal, with less complications such as oxidation, porosity, and overheating that ultimately caused more distortion of the final framework.[41] Nickel- and cobalt-based alloys were selected for this study as they are used in fabrication of long span bridges, partial denture frameworks, and implant single unit restorations.

Significant difference ($P < 0.05$) in the weld strength of these alloys was observed with a higher mean weld strength of Co-Cr group (mean strength: 898 MPa) when compared to nickel-chromium alloy group (mean strength: 690 MPa). Hence, the null hypothesis regarding flexural strength of both groups was declined. Similar findings was observed in a study done previously assessing the weld strength using conventional brazing, TIG, and laser welding,[17,42] whereas another study[43] found that the Ni-Cr group exhibited higher flexural strength compared to Cr-Co group. Hence, the results obtained should be used with caution.

Based on the present findings, Co-Cr alloys can be used as alternatives to Ni-Cr alloys that can occasionally cause skin

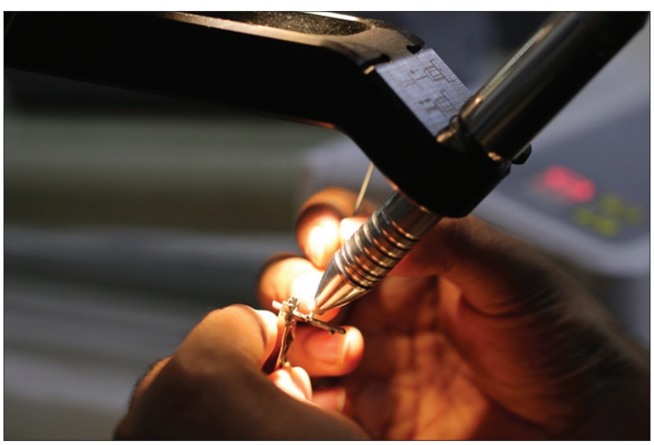

Figure 2: Tungsten inert gas welding process

Independent Samples Test						
		Levene's Test for Equality of Variances				
		F	Sig.	t	df	Sig. (2-tailed)
strength	Equal variances assumed	2.630	.122	-2.884	18	.010
	Equal variances not assumed			-2.884	14.718	.012

Figure 4: Statistical analysis for calculating the mean flexural strengths

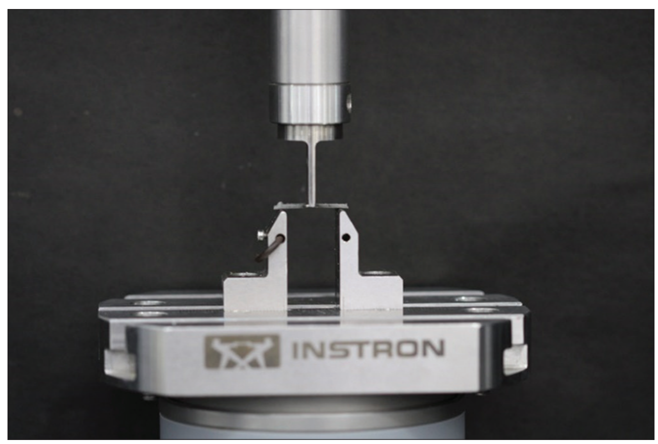

Figure 3: Three-point test using universal testing machine for evaluation of weld strength

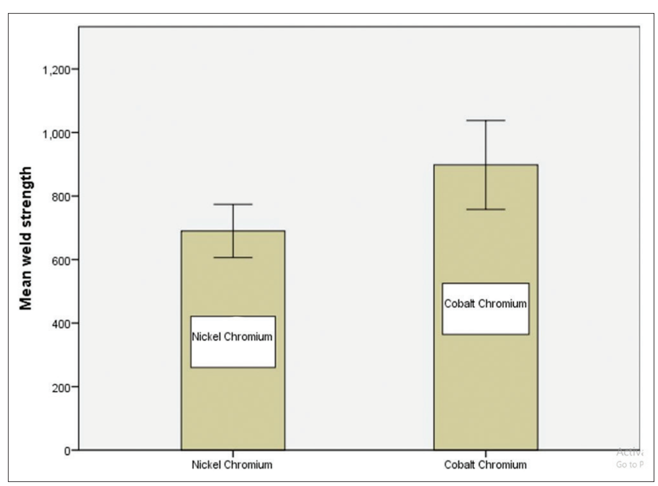

Figure 5: Bar graph depicting the weld strength of both groups. Higher weld strength was observed with the Co-Cr group, Co-Cr: Cobalt-chromium

reactions and hypersensitivity for producing cast partial denture frameworks along with dental implant frameworks. However, further research in this field regarding the properties of these materials in clinical practice is anticipated. Within the limits of the study, this study gives valuable evidence on the weld strength of these base metal alloys to enable clinicians in better decision-making regarding material aspects and choosing the right material for planning the treatment.

CONCLUSION

The welding strength of base metal alloys by TIG welding was better than the bond strength of these materials using the conventional brazing process or laser welding. Co-Cr alloys exhibited higher flexural strength than the Ni-Cr groups, thus making Co-Cr alloys an alternative to Ni-Cr alloys for the fabrication of long span dental frameworks.

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Conflicts of interest
There are no conflicts of interest.

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