Effect of firing cycle and surface finishing on the sag resistance of long-span metal ceramic framework using base metal alloys—an in vitro study

Maj Poonam Prakash*, Col DSJ D'Souza[†], Lt Col Manjit Kumar (Retd)[#], Col M Viswambaran**

ABSTRACT

BACKGROUND

The search for the ideal restorative material or combination of materials in dentistry is still the subject of modern dental research. In clinical practice, there are increased numbers of ceramo-metal restorations being fabricated which replace multiple missing teeth in a single framework. The literature is scanty with regard to investigations of the 'sag' resistance of base metal alloys commonly used for ceramo-metal restorations and specifically for long-span restorations.

An in vitro study was carried out to investigate the effects of surface finishing and simulated porcelain-firing on the sag resistance of long-span ceramo-metal frameworks using base metal alloys.

METHOD

Four types of alloys were used. A total of 80 samples were selected for the study and they were divided into four groups of 20 samples each. 'As cast' metal specimens in group I, group II and with surface finishing in group III and group IV. Each test sample was mounted on the sample holding accessory of the custom made thermo mechanical analyser and subjected to three firing cycles. Each sample was evaluated for the sag-related deflection recorded by the dial gauge with an accuracy of 1 μ m. The data recorded was subjected to a statistical analysis using unpaired *t*-test to compare the relative difference in the sag-related deflection values.

RESULTS

It was observed that the values for sag-related deflection were significantly less for the 'as cast' samples of all the alloy groups. Nickel-chromium (Ni-Cr) and cobalt-chromium (Co-Cr) exhibited value of 19.4 μ m and 14.8 μ m, respectively.

CONCLUSION

Among the four groups of alloys tested, Co-Cr based alloy exhibited the least amount of sag-related deflection. The results show that the

sag-related deflection was less in Co-Cr alloys as compared with the Ni-Cr alloys, still Ni-Cr alloys in fixed dental prostheses frameworks are used due to their desirable physical and chemical properties.

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Key Words: base metal alloys; sag resistance

INTRODUCTION

The search for the ideal restorative material or combination of materials is still the subject of modern dental research. However, ceramo-metallic restorations are some of the most widely used fixed restorations in prosthodontics due to inherent properties such as strength, aesthetics, durability, and insolubility in oral fluids.

Ceramo-metallic restoration consists of a complete coverage cast metal crown that fits over the prepared tooth, which is veneered with a layer of fused porcelain. The teeth preparation for these restorations requires considerable tooth reduction so that the porcelain veneer has sufficient thickness to mask the colour of the metal substructure. Dental porcelains are intrinsically hard and wear-resistant materials with excellent aesthetics and biocompatibility. However, they also have poor tensile, shear and impact strengths rendering them somewhat weak and prone to fracture during masticatory function. These shortcomings have been partially overcome by fusing the porcelain to a substructure of ceramic bonding alloy. The oxide layer that forms on the alloy surface plays a key role in bonding metal to ceramic. In most alloys tin, indium, and zinc are base elements used for oxide formation.¹

The alloys and porcelains used for the fabrication of such restorations have specific requirements. Firstly, both the alloy and ceramic must have coefficients of thermal expansion that are closely matched, with alloy having a slightly higher value to reduce any undesirable residual tensile stresses in the porcelain. Secondly, alloy should have a high proportional limit and high modulus of elasticity. The metal framework must not melt during firing of porcelain and must also resist thermally induced stresses which can produce deformation due to 'sag' phenomenon during porcelain-firing.²

*Graded Specialist (Prosthodontics), MDC Meerut, [†]Commanding Officer, 200 MDC, C/o 56 APO, [#]Professor, Division of Prosthodontics, Genesis Institute of Dental Sciences & Research, Ferozpur, **Associate Professor, Department of Dental Surgery, AFMC, Pune – 40.

Correspondence: Maj Poonam Prakash, Graded Specialist (Prosthodontics), MDC Meerut.
E-mail: pnmpakash@yahoo.co.in

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'Sag' is the deformation potential of long-span metallic substructures at porcelain-firing temperatures under the influence of its own mass. For a given thickness, a higher mass of the prosthesis is related to greater flexural stress and thus greater flexural creep. Creep usually occurs as the temperature approaches within a few hundred degrees of the fusion range of the alloy.³

Sag resistance is the ability of a dental alloy to resist the flow under its own weight during porcelain-firing and soldering. It is particularly important in long-span bridges, where due to increased weight of the prosthesis, the porcelain-firing temperatures may cause the unsupported alloy substructure to deform permanently which results in an ill-fitting restoration. Longer span frameworks and those with small connectors are more susceptible to creep-induced dimensional changes due to increased bending stresses.⁴⁻⁶

The 'sag' phenomenon affecting the metallic substructure is of vital importance to the overall fit of ceramo-metal restorations. Occlusal and marginal discrepancies which occur as sequelae of porcelain-firing cycles lead to misfit, marginal leakage, secondary caries, and periodontal problems.

Most of the studies have been carried out to evaluate the sag phenomenon in respect to short-span restorations. In clinical practice, there are increased numbers of ceramo-metal restorations being fabricated which replace multiple missing teeth in a single framework. There is not much literature available with regard to investigations of the 'sag' resistance of base

metal alloys commonly used for ceramo-metal restorations and specifically for long-span restorations.

It has also been documented that cold working and casting-induced stresses can have a synergistic effect on the distortion of metal ceramic castings.⁶ An in vitro study was, therefore, undertaken to investigate the effects of surface finishing and simulated porcelain-firing on the sag resistance of long-span ceramo-metal frameworks using base metal alloys and to recommend the choice of alloy/alloys for use with long-span ceramo-metallic frameworks.

MATERIALS AND METHOD

A preformed 1 mm thick, pure acrylic resin sheet was used to fabricate the patterns for casting. It was cut into desired dimensions simulating a long-span framework, i.e. 40 mm in length and 6 mm in width using a fine jeweller's saw. Around 80 frameworks were fabricated using standardised casting technique by the single operator. Patterns were invested with graphite-free phosphate bonded investment (Bellasan®, BEGO and Bremen, Germany) and cast using four different commercially available base metal alloys, viz. (1) Wiron 99® (BEGO, Bremen, Germany): a nickel-chromium (Ni-Cr) molybdenum ceramic bonding alloy; (2) 4all® (IVOCLAR, Vivadent, Germany): a Ni-Cr molybdenum ceramic bonding alloy; (3) d.SIGN 30® (IVOCLAR, Vivadent, Germany): a cobalt-chromium (Co-Cr)

Figure 1 Different types of alloys, viz. Wiron 99®, 4all®, d.SIGN 30®, and Wirobond SG®.

Figure 2 'As cast' samples nickel–chromium and cobalt–chromium.

Figure 3 Custom made thermo mechanical analyser (assembled).

molybdenum ceramic bonding alloy; (4) Wirobond SG® (BEGO, Bremen Germany): a Co–Cr molybdenum ceramic bonding alloy (Figure 1). Forty samples were cast using the Ni–Cr alloy and the rest were cast using the Co–Cr alloy.

After divesting, all the samples were checked for dimensional accuracy and any visible defects. Finally, a total of 80 samples were selected for the study. These 80 samples were divided into four groups, i.e. two of Ni–Cr and two of Co–Cr (Figure 2). In each of these four groups, there were 20 samples. The cast metal specimens which were totally free from defects were put in group I 'as cast' (without modifications). The samples which required modifications were finished, polished, and were put in group II (with surface finishing).

Table 1 Protocol for simulated porcelain-firing cycle.

	Firing temperature	Temperature rise (/min)	Holding time (min)
Opaque firing	950°C	80°C	1
Dentine firing	920°C	80°C	1
Glaze firing	900°C	80°C	1

All test specimens were then blasted with 250 µm alumina for five seconds in a sand blasting unit (Korostar Z®, BEGO and Bremen, Germany). This was done to simulate normal procedures of ceramo-metal fabrication. Twenty samples of each of the four alloys were prepared and finished following the abovementioned standardised procedure to the dimensions of 40×6×1 mm³. The sag resistance of these samples were evaluated using the custom made thermo mechanical analyser (TMA) with accessories (Figure 3).

Each test sample was mounted on the sample holding accessory of the custom made TMA and subjected to three simulated porcelain-firing cycles as per the protocol (Table 1). A static load of 0.5 N was applied using a 3 mm diameter glass ball point probe throughout each of the firing cycles.

For each cycle, the dimensional change of the test sample at its point of contact with the glass point probe was recorded and then plotted against the controlled rise in temperature. Each sample was evaluated for the sag-related deflection recorded by the dial gauge with an accuracy of 1 µm in the custom made TMA (Figure 4). The values of sag-related deflection were recorded for each sample at different temperatures of the firing cycles.

To confirm the accuracy of results, the resultant dimensional changes were also verified after cooling the samples to room temperature. The results obtained were then tabulated and subjected to statistical analysis using unpaired *t*-test to

compare the relative difference in the sag-related deflection values between the four alloy groups.

RESULTS

This study evaluated the effect of firing cycle and surface finishing on the sag resistance of four commonly used brands of beryllium-free base metal ceramic bonding alloys used in long-span metal ceramic frameworks 'as cast' and after finishing. The sag-related deflection occurred in the group 1 alloys, i.e. Wiron 99®, 4all®, d.SIGN 30®, and Wirobond SG® were 19.4 µm, 23.3 µm, 17.4 µm, and 14.8 µm, respectively, and after finishing (group 11) were 22.2 µm, 24.7 µm, 19.3 µm, and 19.1 µm, respectively (Table 3). It was observed that the values

for sag-related deflection were significantly less for the group 1 ('as cast') samples compared to alloys with modifications (group II). Wiron 99® (Ni-Cr) and Wirobond SG® (Co-Cr) exhibited a value of 6.29. The *P* value was <0.0001 which was statistically significant. Comparison between groups revealed that Co-Cr alloys shown less deflection compared to Ni-Cr alloys (Table 3).

DISCUSSION

Veneering metal restorations with porcelain had several problems. Acceptable restorations require the alloy and porcelain to be chemically, thermally, mechanically, and aesthetically compatible. Chemical compatibility implies a bond strong enough to resist both transient and residual thermal stresses and mechanical forces encountered in clinical function. Thermal and mechanical compatibility include a fusing temperature of porcelain that does not cause distortion of the metal substructure, along with some degree of match of thermal expansion coefficients.

Earlier gold alloys were used for ceramo-metal restorations. But these alloys had certain disadvantages like low modulus of elasticity and poor sag resistance during the porcelain-firing cycle which led to use of base metal alloys for fixed restorations.⁷⁻¹⁰

Figure 4 Dial gauge reading after three simulated porcelain-firing sequences.

Table 2 Wiron 99® and Wirobond SG® 'as cast'.

Observed	Ni-Cr 'as cast' (Wiron 99®) mean±SD (n=10)	Co-Cr 'as cast' (Wirobond SG®) mean±SD (n=10)	<i>t</i> value	<i>P</i> value
Sag (µm)	19.4±1.51	14.8±1.75	6.29	<0.0001

Co-Cr: cobalt-chromium, Ni-Cr: nickel-chromium, SD: standard deviation.

Figure 5 Bar diagram showing mean of sag-related deflection of 'as cast' samples of Wiron 99® (Ni-Cr) and Wirobond SG® (Co-Cr).

Table 3 Evaluation of sag resistance of alloys.

Ni-Cr observed sag (µm)	'As cast' mean±SD (n=10)	With surface finishing mean±SD (n=10)	<i>t</i> value	<i>P</i> value
Ni-Cr (Wiron 99®)	19.4±1.51	22.2±1.55	4.10	<0.01
Ni-Cr (4all®)	23.3±1.42	24.7±0.95	2.59	<0.05
Co-Cr (d.SIGN 30®)	17.4±1.65	19.3±1.95	2.36	<0.05
Co-Cr (Wirobond SG®)	14.8±1.75	19.1±1.66	5.63	<0.0001

Co-Cr: cobalt-chromium, Ni-Cr: nickel-chromium, SD: standard deviation.

Most of the non-precious alloys used for ceramo-metal restorations are based on Ni–Cr but a few Co–Cr and iron-based alloys are also available. These alloys are based on >75% by weight of base metal elements or <25% by weight of noble metals. The higher fusion temperatures of Ni–Cr and Co–Cr base metal alloys has been a factor that contributed to their superior sag resistance, in comparison to the noble metal alloys. The Ni–Cr alloys have the high elastic moduli and this decreases flexibility to less than half that of a framework of the same dimensions made of high gold alloy.⁵

The initial or the ‘as cast’ fit of metal ceramic restorations deteriorates during the high temperature firing cycles employed for porcelain veneer application which results in an increased space between the restoration and prepared tooth which provides a niche for bacterial plaque which may lead to caries and gingival inflammation.^{7,8}

Another important aspect is the surface design and finishing. The surface must be designed to minimise stress concentration which results from the stress raisers. It has been observed that individually neither the release of the casting nor the cold working induced stresses were sufficient to cause significant distortion of the metal during their thermal cycling. However, a synergistic relationship appears to exist between the two.⁹

Long-span frameworks should be well supported during the firing cycle to prevent this sag which leads to distortion. The techniques include different types of sagger trays, different porcelain application techniques, pre- and post-soldering and the use of one piece castings.⁸

If distortion is minor, it necessitates chair side adjustments of the retainers and the need to repeat the casting, when major distortion has taken place. This is more relevant in cases of long-span fixed dental prostheses.

There were numerous drawbacks in the various studies carried out in the past. Most of the work was done in respect to short-span metal frameworks and not long-span. Majority of the work had been carried out for Ni–Cr alloys and not Co–Cr alloys. Other drawbacks include the slower heating rate, absence of an isothermal hold at final test temperatures, lower sensitivity of measurements, and static instead of dynamic measurements of thermal creep.

The thickness of the sample selected for this study was 1 mm which was a better representative of the thickness of a porcelain alloy substructure, actually used in dental practice. The firing cycles at temperature of 900°C, 920°C, and 950°C were selected, as these closely represented the porcelain-firing cycles used in the laboratory. A mid-span load of 0.5 N load was applied to the metal substructure with the glass point probe during the entire heating cycle to represent the weight of ceramic material over the alloy substructure, which in turn, would affect the sag dynamics at elevated temperature.

A controlled heating rate of 80°C/min, similar to a porcelain-firing cycle, was used to heat the furnace from 35°C to 950°C (dynamic mode of heating) and the temperature was held constant at 950°C for one minute (Isothermal hold). The mid-span

deflection of the glass point probe at its point of contact with the test sample was measured to a sensitivity of 1 µm.

CONCLUSION

Sag-related deflection was less in ‘as cast’ samples as compared with ‘surface finished’ samples of both the alloy groups of Ni–Cr and Co–Cr. The values were less in Co–Cr alloys than in Ni–Cr alloys. Among the four groups of alloys tested, Co–Cr-based Wirobond SG® alloy exhibited the least amount of sag-related deflection. These values were statistically significant.

Although, the results show that the sag-related deflection was less in Co–Cr alloys as compared with the Ni–Cr alloys, the widespread use of Ni–Cr alloys in fixed dental prostheses frameworks are used to desirable physical and chemical properties like high modulus of elasticity, sag resistance, increased stiffness, and high tensile strength.

On the other hand, Co–Cr alloys with increased hardness and rigidity make occlusal adjustments, polishing, crown removal, and endodontic opening more difficult. Laboratory labour costs are often higher because of the hardness of these alloys increases the working time. Also the higher cost and the availability make them less popular as compared with the Ni–Cr alloys for porcelain fused to metal fixed dental prostheses.

Within the limitations of the study, 40 mm long metal tab, the alloys were subjected to simulated porcelain-firing cycles and results of sag-related deflection were measured. However, further research is recommended with a standardised die of a long-span situation having abutments and pontics and actual porcelain application in clinical situations to determine the sag measurements. Also the evaluation of prostheses ‘in vivo’ under functional load is essential to substantiate the results.

Intellectual Contributions of Authors

Study concept: Maj Poonam Prakash

Drafting and manuscript revision: Col DSJ D’Souza, Col M Viswambharan

Statistical analysis: Lt Col Manjit Kumar (Retd)

Study supervision: Col DSJ D’Souza, Lt Col Manjit Kumar (Retd)

CONFLICTS OF INTEREST

None identified.

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Journal scan

Beckett A, Savage E, Pannell D, Acharya S, Kirkpatrick A, Tien HC. Needle decompression for tension pneumothorax in tactical combat casualty care: do catheters placed in the midaxillary line kink more often than those in the midclavicular line? *J Trauma* 2011;71(5 Suppl 1):S408–S412.

Tactical Combat Casualty Care (TCCC) is a system of prehospital trauma care designed for the combat environment. Needle decompression (ND) is a critical TCCC intervention, because previous data suggest that up to 33% of all preventable deaths on the battlefield result from tension pneumothoraces. There has recently been increased interest in performing ND at the fifth intercostal space in the midaxillary line to prevent complications associated with land marking second intercostal space in the midclavicular line site. The authors developed a model to assess whether catheters placed in the midaxillary line for decompressing tension pneumothoraces are more prone to kinking than those placed in the midclavicular line because of adducted arms during military transport. To simulate ND, authors secured segments of porcine chest walls over volunteer soldiers' chests and placed 14-gauge, 1.5-inch angi catheters through the porcine wall segments which were affixed to either the midaxillary or midclavicular location on the volunteers.

Then they assessed for occlusion and kinking, by flow of normal saline (NS) through the angi catheter in situ. The angi catheter was then transduced using standard arterial line manometry, and the opening pressures required to initiate flow through the catheters were measured. The opening pressures were then converted to mmHg. They also assessed for catheter occlusion after the physical manipulation of the patient, by simulated patient transport. The authors observed that there was a significant pressure difference required to achieve free flow through the in situ angi catheter between the fifth intercostal space mid-axillary line vs the second intercostal space midclavicular line site (13.1 ± 3.6 mmHg vs 7.9 ± 1.8 mmHg). This study at Canadian Field Hospital suggests that the 14-gauge, 1.5-inch angi catheter used for ND in the midaxillary line may partially and temporarily occlude in patients who will be transported on military stretchers. The pressure of 12.8 mmHg has been documented in animal models as the pressure at which haemodynamic instability develops. The authors concluded that this may contribute to the reaccumulation of tension pneumothoraces and ultimate patient deterioration in military transport.

Contributed by
Col MM Harjai*

*Senior Advisor (Surgery and Paediatric Surgery),
Command Hospital (SC), Pune – 40.

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