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Evaluation of Physical Properties and Casting Accuracy of Chrome-cobalt Alloys with Different Casting Systems and Investments

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Abstract: *Castability and loss of mass from Co-Cr castings after polishing had been evaluated. Casting systems of centrifugal and vacuum types and two types of phosphate-bonded investments were used. Cast plates were weighed before and after polishing (limit value of 100 ± 20nm was confirmed with AFM) to measure mass loss (%). Surface layer of cast specimens and porosity of investments was observed. Loss of mass of cast specimens and surface reaction layer was not influenced either by casting systems or by porosity of investments. Investments with more porous structure and centrifugal type casting system had shown significantly improved castability.*

Keywords: chrome-cobalt alloys, casting systems, investment materials, castability, mass loss

1. INTRODUCTION

The high elastic modulus and hardness of base metal alloys are adequate for long-span metal-ceramic restorations or removable partial dentures (RPDs). The mechanical properties of base metal alloys and low cost make them attractive. Base metal alloys, such as cobalt-chromium (Co-Cr) have been widely used in fabrication of fixed and removable partial denture (FPD and RPD) frameworks since being introduced to dentistry in 1929.[1,2] The increase in the cost of noble metallic alloys in the 1970s led to the development and increasing clinical use of basic metal alloys to make crown and fixed partial prosthesis infrastructures.[3] The other primary physical-chemical properties of base metal alloys include a lower density than gold alloys, a particularly useful feature in fabricating bulky or extensive prostheses; and a modulus of elasticity that is nearly twice that of gold alloys, providing FPD and RPD with the advantage of maintaining rigidity with less bulk.[4] These properties allow improved aesthetics and physiological contouring and the development of a suitable occlusion with less tooth structure reduction.[4]

Dental casting system aims to provide a metallic copy of the wax pattern as accurate as possible. Nevertheless, a wide range of variables may influence the final result and predictable outcomes are hardly achievable. While casting dental prostheses, problems frequently observed are incomplete casting and internal porosity.[5] One of the main factors leading to these defects is the pattern of casting force exerted on the molten metal.[6] All casting machines accelerate the molten metal into mould either by centrifugal force or air pressure.[7] The presence of porosity within the mould prior to casting is also important to avoid back-pressure defects. This porosity can contribute to the permeability of the mould.[8] Thus, evaluation of castability which means the ability of an alloy to reproduce mould details, had been frequently performed. In previous study, simulated steel crown with dimensions as given in the Australian Standard (AS) 1620 (1985) was used to evaluate castability of unalloyed titanium using different casting machines.[9] Fabricated frame-works on Kennedy Class II, Division 1 maxillary RPD was used for evaluation of castability and surface roughness of pure titanium and cobalt-chromium denture frameworks.[10]

Surface roughness of dental cast prostheses may also vary with different casting environment. Surface roughness of cast prostheses significantly influence the adhesion of supragingival bacterial plaque, incidence of dental caries, gingivitis and periodontal disease.[11,12] Increase roughness had been observed using conventional casting procedures.[13] In previous study, an average roughness of Ra 0.09 ± 0.01 μm was adopted as a "limit value" to establish the final acceptable polishing condition.[13] It has been reported that greater surface roughness requires additional finishing and polishing procedure.[14] However, technical shortcomings, such as the increased difficulty of grinding and polishing procedures with conventional chair side and laboratory instruments restricted the use of base metal alloys in dental practice.[4,15] An earlier investigation demonstrated that there is considerable loss of metal structure from RPD framework during finishing and polishing resulting in poor fit of retentive clasp arm and improper contact at the tooth-clasp interface,[16] thus affecting the stability and retention of the RPD.[17] Due to hardness of these alloys, special equipment is required for cleaning and smoothing the restoration after casting, which considerably limits these procedures in dental offices. The hardness of the cast alloy is influenced by their composition, casting method and reaction of molten metal with the elements of investment material.[18,19] The resultant reacted layer is termed as α case which is undesirable in terms of surface roughness and the fit of the appliance.[20]

As several casting systems are based on different principles, cast specimens need to be evaluated using different casting systems. Thus, the purpose of the present research was to evaluate castability of Co-Cr alloys and to determine the loss of metal structure from cast specimens after polishing using centrifugal and vacuum type casting systems. In addition surface layer of cast specimens and porosity of the investments was also observed.

2. EXPERIMENTAL

This is an experimental laboratory study design which is shown in Figure 1. Mesh wax pattern of 25 × 25 mm, with 68 holes (Grids perforated RN III casting, Dentaurum, Ispringen, Germany), used in previous research was selected for evaluating castability of Co-Cr alloys in this experiment.[21] Clear acrylic plates of 10 × 20 × 1.5 mm (Erkodur, Erkodent, Pfalzgrafenweiler, Germany) were prepared for evaluating loss of mass of cast specimens after polishing.

A wax sprue with diameter 2.5 mm and length 6 mm was fixed onto a sprue base (Rapid Ringless System, Bego, Bremen, Germany). All the specimens were invested using 2 types of phosphate-bonded investment: (EPM) (ECOVEST PM, dent-e-con, Lonsee, Germany) and (CSG) (CHROMECAST-SG, Emdin International Co., Irwindale, California) as in Table 1. The investments were mixed according to the manufacturer's instructions.

Table 1: Compositions of investment material.

Code	Brand name (Manufacturer)	Refractory	Binder	Liquid for mixing	L(W)/P ratio
EPM	Ecovest PM (Dent-e-con, Lonsee, Germany)	SiO_2	Phosphate	Special liquid (colloidal silica)	0.14
CSG	Chromecast-SG (Edmin Int. Corp., Irwindale, California)	SiO_2	Phosphate	Special liquid (colloidal silica)	0.15

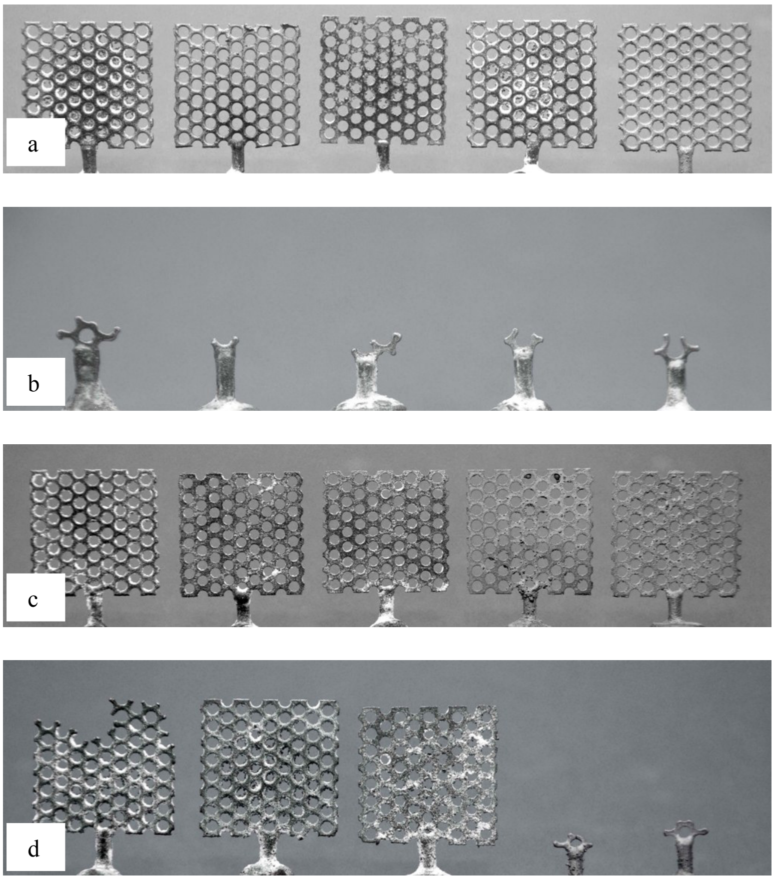

Figure 1: Cast specimens obtained using 2 types of casting systems with 2 different investments, i.e., cast specimen with: a) Centrifugal (FOR)/EPM; b) Vacuum (NAU)/EPM; c) Centrifugal (FOR)/CSG; and d) Vacuum (NAU)/CSG.

Electric furnace (OVMAT 2007, Manfredi, Torino, Italy) was used for burn-out procedure. The specimens were cast with centrifugal (Fornax G/GU (FOR), Bego, Bremen, Germany) and vacuum (Nautilus CC plus (NAU), Bego, Bremen, Germany) casting systems (Table 2). Co-Cr ingot (Remanium GM900, Dentaurum, Ispringen, Germany) was used as cast alloys. All cast specimens were cleaned in sandblast machine (S-U-Prolamat, Schuler Dental, Ulm, Germany) using aluminium oxide particles (250 µm) for 1 min to remove investment residues. Castability was calculated as the percentage of reproduced completed holes of cast specimens compared to the total number of holes of wax pattern as below.

$$\text{Castability} = \frac{\text{number of completely cast segments}}{\text{total holes in wax pattern}} \times 100$$

Table 2: List of casting machines.

Code	Name of machine	Type of casting force	Manufacturer
FOR	Fornax G/GU	Centrifugal	BEGO Bremer Goldschlagerei Wilh. Herbst GmbH & Co., Bremen, Germany
NAU	Nautilus CC plus	Vacuum	

For the evaluation of mass loss, each cast plate was weighed on a precision balance (Dragon 204, Mettler Toledo Inc., Greifensee, Switzerland) before and after polishing with 320–1000 grit sandpaper (Hermes, Hermes Abrasives Ltd., Virginia, USA). The polished surface of cast plate was assessed with atomic force microscopy, AFM (Q-Scope 250/400 Nomad, Ambios Technology Inc., Santa Cruz, USA) at 3 different sites of the cast plate. The scan size (48 × 48 μm) was maximised and the number of scan lines was 50. The cast plates were polished until acceptable surface roughness value of Ra 100 ± 20 nm was attained. This value was then adopted as a "limit value" to establish the final acceptable polishing condition for subsequent tests. Each cast plate was carefully polished, alternating with roughness measurements, until the limit value was achieved. Then, the specimens were weighed again. Loss of mass related to the initial mass was determined as the structure needed to be grinded for optimal polishing.

$$\text{Loss of mass} = \frac{\text{Weight before polishing} - \text{Weight after polishing}}{\text{Weight before polishing}} \times 100$$

Cast specimens obtained from the 2 types of casting systems were cut at the centre of the sprue and cleaned in sand blast machine for 1 min. The sprue was embedded in acrylic resin, consecutively polished with 320–1000 grit sandpaper. To observe surface reacted layer of cast specimens representative cast samples from each of the casting system and investment were observed under Scanning electron microscope (Phenom™, Eindhoven, Netherlands). Sample of each investment materials (EPM and CSG) which was fired in the furnace according to the heating schedule, was cut and the inner surfaces of the investments were observed using the microscope (Leica DMLM, Leica Microsystems, Bensheim, Germany) to evaluate porosity of investment. Three pictures were saved from 3 different sites of each of the sample.

Five specimens of mesh type and plate type were prepared and cast with different casting systems using each of the investment material. Differences in castability, mass loss (%) were analysed using Mann Whitney test ($\alpha = 0.05$), statistical software SPSS 12.

3. RESULTS AND DISCUSSION

Significantly ($p = 0.001$) improved castability with EPM and CSG was observed using centrifugal system (74.12 ± 25.84% and 97.65 ± 4.48% respectively) than vacuum system (0.29 ± 0.66% and 43.53 ± 40.24% respectively); as shown in Figure 1 and 2. Castability with CSG was found significantly ($p = 0.012$) higher than EPM using vacuum system. The loss of mass after polishing was not significantly different ($p = 0.070$) using both casting systems; as shown in Figure 3. SEM pictures of the cast specimens from each casting system are shown in Figure 4. Similar type of thickness (11.3 μm) of reacted layer was observed. More porous structure was observed with CSG as shown in Figure 5.

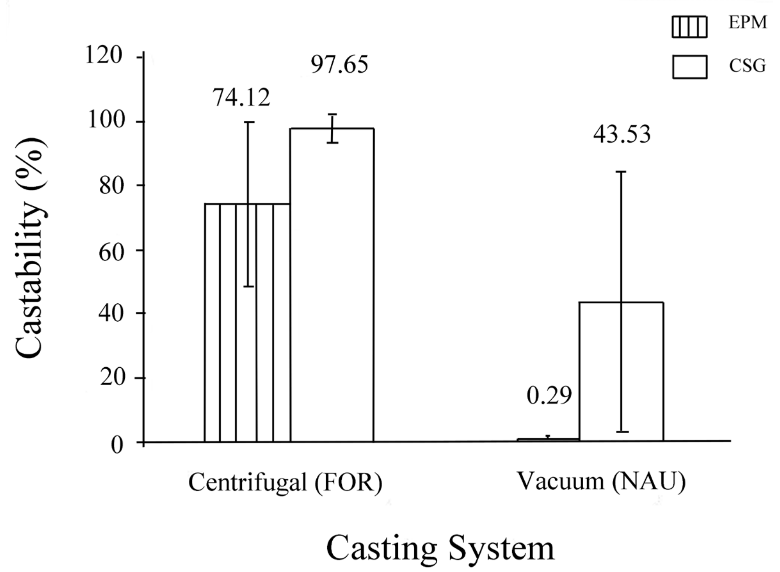

Figure 2: Castability of Co-Cr alloy using 2 types of casting systems with 2 investments.

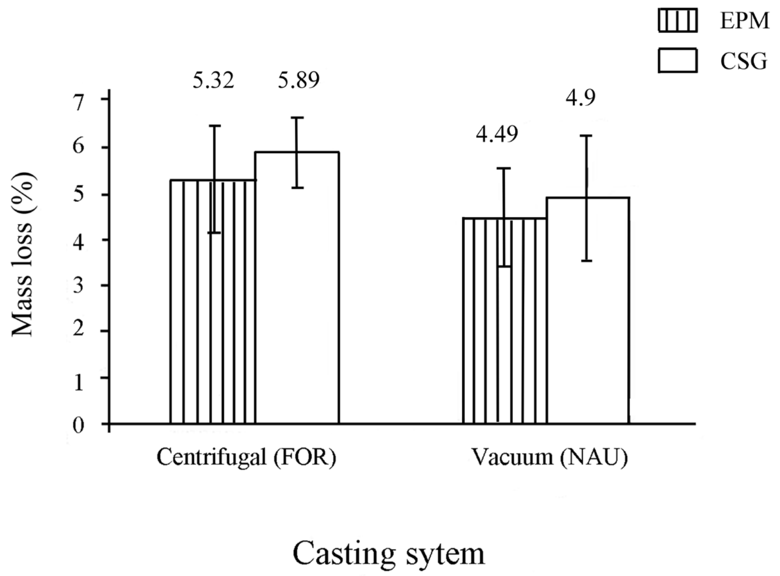

Figure 3: Mass loss (%) after polishing of cast plates.

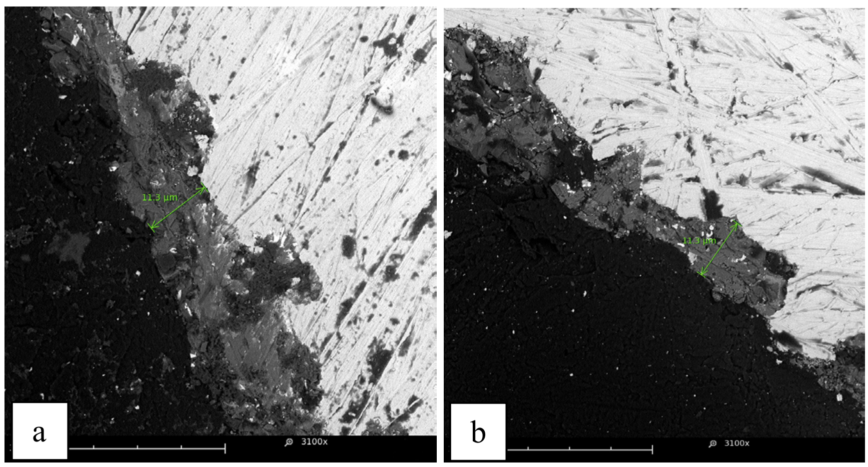

Figure 4: SEM picture showing reaction layer thickness: a) cast specimen from centrifugal (FOR); and b) vacuum type (NAU) casting systems.

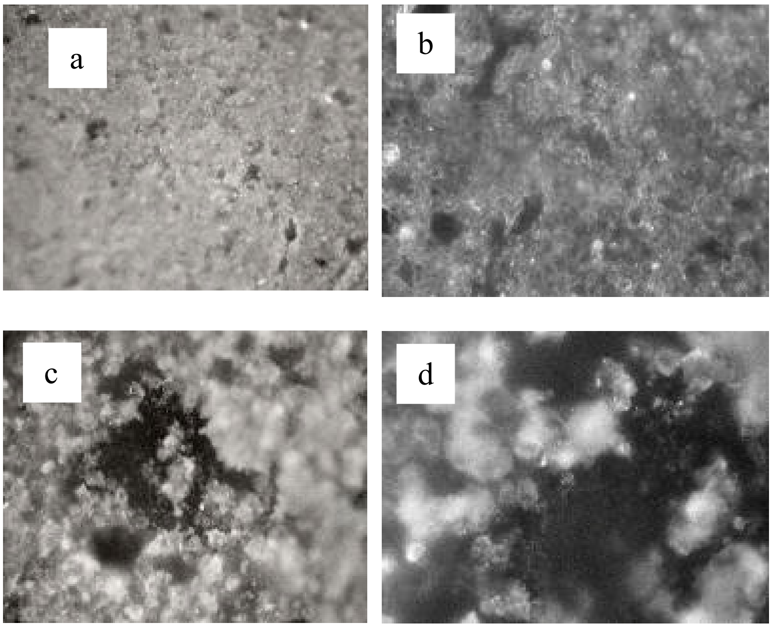

Figure 5: Porosity of investments viewed under microscope for: a) EPM under 20X magnification; b) EPM under 50X magnification; c) CSG under 20X magnification; and d) CSG under 50X magnification.

Castability of Co-Cr alloy is an important factor to be considered, since it is directly related to a precision cast restoration. The wax pattern which was used to evaluate castability in this study was first proposed by Watanabe et al. for evaluating castability of titanium.[21] Among the advantages of the method used in this study are: ease of preparation of the casting pattern, the pattern can be burned out in furnace using the usual procedure for wax elimination, size and shape of specimens can be standardised and castability could be evaluated by simply counting the number of completely formed holes.

Casting system has significant effect on castability. Most of the findings on castability were observed with pure titanium or with titanium alloys and limited studies were conducted on evaluation of castability using Co-Cr alloys with different casting system. Better castability of pure titanium was observed in a previous study using centrifugal system than a pressure casting system using investments with less permeability.[8] Although minimum porosity was observed with EPM investment, results of castability was comparable with CSG investment when casting was performed with centrifugal casting system. This observation was explained as followed: as the centrifugal force applies to the molten metal, and the mould gases can exhaust from sprue in moulds without permeability in the centrifugal casting.[22] On the other hand, significantly lower castability with vacuum system was found irrespective of investment materials probably due to incomplete mould filling. Similar problem was also observed in a previous study and was explained as an occasional problem with low casting pressure difference. Moreover, it was found that centrifugal casting system can exert approximately 4–6 times more force on metal than the pressure casting system.[23] Inadequate mould filling with EPM investment was probably due to the back pressure effect from gas retention with less porous structure of the investment. The less porous structure might also be related with reduced permeability of investment. A study of mould filling of titanium castings found that improved cast specimens were obtained when a highly permeable investment was used,[6] however, improved castability was also reported with less permeable investment.[8,24] Although recent studies[8,25] on the effects of porosity/permeability of investments on castability of titanium was found not significant, castability result considering permeability of investment with Co-Cr alloys may be different due to the different properties of the alloys than titanium. Further studies are necessary to evaluate the effect of porosity and permeability of investment in relation of castability of Co-Cr alloys.

Several factors related to casting systems also influence the castability of the cast specimens. Thus controlling these factors is important to have predictable outcomes. Within the limitation, only the variable casting system was evaluated thus different results might be obtained using different study design. Further studies should investigate other factors which were not considered in this study, such as investment material, casting temperature, spruing and mould temperature.

Finishing and polishing procedures can compensate for greater surface roughness resulting from casting procedures. However, the removal of additional material to provide a clinically acceptable finish can affect the fit[15] and the resistance of the metal structure.[26] Thus, the present study was focused in evaluation of loss of mass due to polishing of cast specimens. The mean loss of metal due to polishing up to threshold limit was lower for vacuum system although the result was not significantly different compared with centrifugal system. It is expected that fitness changes of cast specimen due to polishing would be the same using both of the casting systems. The similar findings had been observed in a previous study while casting under controlled and uncontrolled atmosphere.[13] Resultant reacted layer on cast surface (α-case) which is considered to be responsible for higher hardness of the cast specimen might be a contributing factor on final finishing and polishing procedures. The SEM observation on surface reacted layer of the cast specimens of each casting system was the same. Thus, SEM findings of the present study support the result of loss of metal mass which was found similar among the 2 types of casting systems. Considering the investments properties, the less porous investments had shown lower mass loss (%) comparing to the higher porous CSG investment regardless of casting systems although the differences were not significant. The presence of trapped air inside more porous investments thus did not significantly react with molten metal surface during casting. Further studies on this aspect, such as electron probe microanalysis (EPMA) to evaluate changes in composition of the alloys after different casting conditions are required.

A narrow range of surface roughness (100 ± 20 nm) of cast specimens could be precisely measured using AFM. Applications of AFM to metal specimens allow quick and easy generation and quantification of images in the sub-micrometer and nanometer range. Within the limitations, the specimens were polished on only one surface, thus preventing direct comparison to the clinical situation where the surface of an RPD is polished on both external and intaglio surfaces.

4. CONCLUSION

The effects of casting systems on castability and mass loss (%) of Co-Cr alloys have been evaluated and investment moulds before casting conditions have been observed for porous structures. The results indicate that castability or mould filling was significantly better with higher casting force and with more porous structure of the investment. However, the loss of mass after polishing of cast specimens was similar with both casting systems and investments which indicate casting systems and porosity of investments did not influence to achieve acceptable level of polished cast specimen.

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