INVESTIGATION INTO THE ACCURACY OF COBALT-CHROMIUM DENTURE CASTINGS

by

DRG. BOB SOEBIJANTORO, MSc.

FACULTY OF DENTISTRY - AIRLANGGA UNIVERSITY

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Introduction

Cobalt-chromium alloys have been applied in the field of dentistry as partial denture castings for many years. Their composition and properties have been investigated by many workers (1,3,16,20 and others). These base metal alloys have largely replaced gold alloys in the fabrication of removable partial denture frameworks, despite the fact that gold alloys possess certain advantages in terms of physical and mechanical properties.

Certain problem however have been encountered in connection with casting cobalt-chromium alloys and it is a common clinical experience that a varying percentage of frameworks fabricated from these alloys have to be rejected due to inaccuracy in fit (2,7). Although this may occur as a result of faulty handling (both in the clinic and in the laboratory), there does exist an inherent inaccuracy in the material in that it undergoes casting shrinkage of the order of 1.8 to 2.0 per cent (12), 2.0 per cent (4), 2.15 to 2.33 per cent (7,8). In a study of dimensional changes during casting, Pulskamp (17) showed that the cross arch measurements of polished frameworks of cobalt-chromium alloy tested were subject to a mean expansion of 0.79 per cent, while the antero posterior measurements showed a mean expansion of 0.46 per cent when comparing the frameworks to their master casts.

The reason for a large spread in reported values of the dimensional changes following casting of these alloys may be due to the complex geometry of individual castings upon which the dimensional changes were measured [18], the composition of the alloy, the casting techniques [15], the method of spruing [14,15.18] and the compressive strength of the investments [7,10,11,13,14]

The purpose of this study was to assess the dimensinal changes of cobalt-chromium denture castings which may occur under practical laboratory condition. It was necessary therefore to consider the changes which may occur at each stage of the casting procedure, which include :

- construction of the refractory cast
- preheating and adsorbing beeswax on the surface of the refractory cast
- formation of the wax pattern
- production of the casting.

Method of Study

A stone master cast of a bilateral free end saddle preparation was used for this part of the investigation. Cylindrical holes were drilled in the saddle areas of the cast to provide reference marks from which any linear dimensional change could be measured. The position of the cylindrical holes are shown in Figure 1. The length measurements between any two of the holes were determined using the measurescope*, which is essentially a travelling microscope which can be used for accurate measurement in the vertical and horizontal planes. All measurements were repeated six times and a mean obtained which was used as the base line unit in the study.

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* Nikon Measurescope, Nippon Kogaku K.K., Japan.

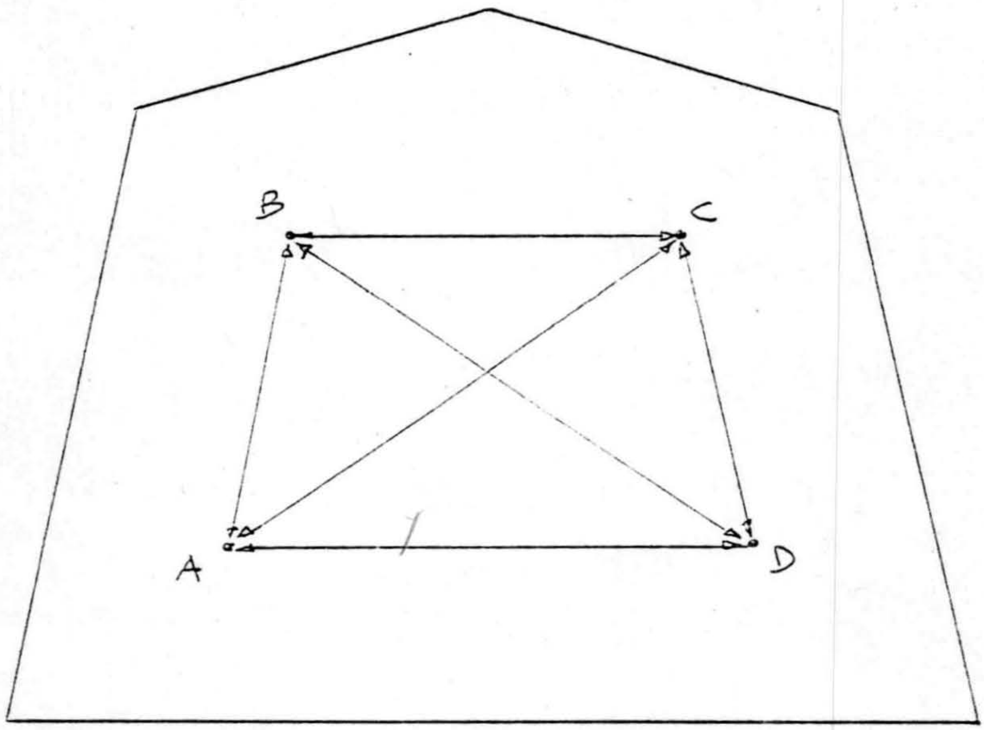

Figure 1. The position of the cylindrical holes in the stone master cast.

The Refractory Cast

The duplicating material used in this study was an agar preparation (Metrogel)* and the directions for duplication given by the manufacturer of the material were followed in the preparation of a refractory cast. The material was heated in an enamel sealed pan, until it reached the sol state and was allowed to cool to 42 - 45°C before pouring. The stone cast was soaked in water at room temperature for five minutes before being placed in a flask which was then filled with the duplicating material.

After 60 minutes when the agar material had gelled and was at approximately room temperature, the stone cast was removed from the flask with a rapid movement in order to take the advantage of the elastic properties of the material and to avoid tearing. The phosphate-bonded investment material (Aquavest)** was used to prepare the refractory cast on which the cobalt-chromium casting would be constructed. The material was mixed as recommended by the manufacturer and was vibrated into the duplicating mould and allowed to set at room temperature. When it had reached its final set it was removed from the mould. A total of 10 refractory casts were made in this manner.

The distances between the prepared holes were then measured using the measurescope. Differences between these length measurements in the investment cast and in the stone master cast were determined. From these measurements, the average change was expressed as a percentage of the original length.

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* Metrodent Ltd., U.K.

** Cheperlin & Jacobs Ltd., U.K.

Adsorption of Beeswax

The next stage in casting involves preheating and adsorbing beeswax on the surface of the refractory casts. In this case the casts were put in an oven and heated to 200°C for 2 hours. In the meantime beeswax was liquefied, and following heating, the refractory casts were dipped in the liquefied beeswax, removed, and left to cool in air until room temperature was reached. The length measurements were then repeated on refractory casts after beeswaxing.

The Wax Pattern

A sheet of casting wax* having a thickness of 0.4 mm was used to prepare the wax pattern. Two additional holes were made in the wax on each side of saddles in a similar position to those shown in Figure 1 by means of a needle, and in order to simplify the location of the holes under the microscope for measurement purposes, a larger circle was made around each. Length measurements were then made in antero-posterior cross-arch and diagonal directions similar to those previously made in the master cast.

The Casting

A wax sprue** of 2.5 mm in diameter was attached to each end of the saddle, the four sprues being joined together with a crucible former and positioned in the centre of a casting ring. Aquavest at a water/powder ratio of 14 ml water to 100gm powder as recommended for investing was mixed and vibrated around the wax pattern

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*Green casting wax, Chapperlin and Jacobs Ltd., U.K.

**Profile wax, Chapperlin and Jacobs Ltd., U.K.

and refractory cast in the ring for 2 minutes. After the investment had hardened, the mould was released from the ring and left in air at room temperature until the final set had been reached. It was then stored in a tightly sealed receptacle containing a damp cloth, to minimise any water loss and the casting process was carried out the following day.

Immediately prior to casting the investment mould was placed in a low-temperature furnace and heated to 200°C. It was then transferred to a high-temperature furnace and heated to 1000°C. New metal ingots of cobalt-chromium alloy* were then placed in the crucible of the casting machine** and preheated. No control of the metal temperature other then visual observation by the operator throughout was possible. As soon as the metal had reached a "mushy" consistency, the mould was transferred from the furnace to the casting machine and the casting was completed. The mould with the casting was then allowed to cool in air at room temperature, after which the framework was freed from the surrounding investment and cleaned by sandblasting. No heat treatment of the casting was carried out. The length measurements were then repeated on the fitting surface of the metal framework in order to determine whether there was any dimensional change between the framework and its refractory cast or master cast, and on the outer surface to determine whether there was any dimensional change between the metal framework and the wax pattern. Ten castings were produced in this manner, each using new metal ingots from the same batch number.

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*Croform, Davis, Schottlander and Davis Ltd., England.

**Williams' Inductocast, Williams Gold Refining Co. Inc., Buffalo, New York.

Re-use of Alloy

In order to study whether re-use of alloy may affect the casting accuracy, nine further castings were produced in the same manner using alloy which had already been cast. All of these castings were carried out using the same method as previously described. Any residual investment material was removed firstly from the used metal with the sandblaster. Sufficient quantity of used metal was then put in the crucible in the casting machine without adding any new metal. The casting was completed as previously described. Following removal from the investment mould length measurements were carried out as before.

Results

The values recorded for the measurements from the master cast and the refractory cast before and after beeswaxing are presented in Table 1. The differences between the master cast and the frameworks both using new metal and reused metal are shown in Table 2 and the differences between the wax patterns and the resulting frameworks in Table 3.

In all cases, production of the refractory cast was accompanied by a reduction in antero-posterior, cross-arch and diagonal length measurements. There was therefore evidence of contraction of the refractory cast relative to the master cast in the areas under investigation. When comparing the mean length measurements for the 10 refractory casts prepared this showed a mean contraction of 0.2% for antero-posterior, 0.05% for cross-arch and 0.13% for diagonal measurements.

Table 1. Length measurements of master cast, refractory casts before and after beeswaxing (mm), together with reduction in the mean measurement relative to the master cast.

Measurement	Master cast	Refractory cast before beeswaxing			Refractory cast after beeswaxing		
		Mean	S.D.	Reduction	Mean	S.D.	Reduction
A - B *	13.65	13.63	0.01	0.02	13.60	0.04	0.05
C - D *	19.36	19.32	0.02	0.04	19.27	0.04	0.09
B - C **	33.62	33.61	0.02	0.01	33.58	0.02	0.04
A - D **	48.60	48.57	0.02	0.03	48.43	0.07	0.17
A - C ***	42.69	42.66	0.03	0.03	42.64	0.03	0.05
B - D ***	45.32	45.23	0.05	0.09	45.15	0.11	0.17

Note : * - antero posterior measurement

** - cross arch measurement

*** - diagonal measurement

Table 2. Length measurements of master cast, new metal frameworks and reused metal frameworks (mm) together with reduction in the mean measurement relative to the master cast.

Measurement	Master cast	New metal framework			Reused metal framework		
		Mean	S.D.	Reduction	Mean	S.D.	Reduction
A - B *	13.65	13.44	0.09	0.21	13.52	0.05	0.13
C - D *	19.36	19.16	0.05	0.20	19.09	0.15	0.27
B - C **	33.62	33.45	0.08	0.17	33.44	0.12	0.18
A - D **	48.60	48.17	0.11	0.43	48.16	0.07	0.44
A - C ***	42.69	42.37	0.09	0.32	42.38	0.09	0.31
B - D ***	45.32	44.90	0.12	0.42	44.84	0.15	0.48

Note : * - antero posterior measurement

** - cross arch measurement

*** - diagonal measurement

Table 3. Percentage contraction of the new metal frameworks relative to their wax patterns.

Measurement	Contraction	
	Mean (+)	S.D.
A - B *	1.32	0.64
C - D *	1.44	0.63
B - C **	0.38	0.09
A - D **	0.50	0.07
A - C ***	0.57	0.11
B - D ***	0.38	0.11

Note : * - antero posterior measurement

** - cross arch measurement

*** - diagonal measurement

(+) - each figure represents the mean value of ten experiments.

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Preheating and dipping the cast in beeswax prior to forming the wax pattern resulted in further reductions in length measurements. Expressed as a percentage of the original length (master cast), this gave a reduction of 0.43% for antero-posterior, 0.23% for cross-arch and 0.25% for diagonal measurements.

As it would be expected that any contraction occurring in the refractory cast would be directionally uninhibited it is of some value to determine the total percentage reduction in final dimension of the cast after dipping in beeswax in the areas investigated. This indicated that in regions relating directly to the casting there was a percentage overall reduction after beeswaxing of 0.30% relative to master cast. When the metal frameworks were compared to the master casts it was clear that further contraction had occurred relative to the beeswaxed refractory casts. When comparing the mean length measurements for the 10 resulting frameworks from the master cast, this showed a mean contraction of 1.31% for antero-posterior, 0.69% for cross-arch and 0.84% for diagonal measurements with reference to the master cast.

If it is accepted that the casting shrinkage of the alloy is not subject to directional constraint then the total casting shrinkage can be estimated by determining the difference between the sums of the length measurements of the master cast and the metal framework. This can then be expressed as a percentage. In the present study the percentage casting shrinkage was found to be 0.94%.

Comparisons were also made between measurements recorded for new and used metal casting using a t-test to compare the means, and it was found that there was no significant difference ($p > 0.05$) in dimensional changes either in antero-posterior, cross-arch or diagonal measurements between frameworks constructed from new metal or used metal.

When comparisons were made between the length measurements of the wax patterns and the corresponding length measurements of the metal frameworks, it was also clear that contraction had occured. This was evident as a mean contraction between framework and wax pattern of 1.38 per cent in antero-posterior, 0.44 per cent in cross arch and 0.47 per cent in diagonal measurements (Table 3).

Discussion

From the results presented it is clear that a casting shrinkage relative to the master cast occured in the cobalt-chromium alloy used. This casting shrinkage appears to be a cumulative phenomenon occuring at each stage in the production of the casting commencing with the refractory cast.

The presence of a linear contraction in the refractory cast is difficult to explain, particularly in view of the fact that an expansion on setting of investment material was clearly demonstrated in the earlier study (19). It is probable be however, that the strength of the duplicating mould produced some constraint in the areas under investigation and the majority of the setting expansion occured at the free or non-constrained surface of the material. This would be in agreement with the view expressed by DOOTZ et al.(5) In addition following removal of the master cast from duplicating mould, the elastic recoil of the material may have been accompanied by a degree of stress relief resulting in slight mould contraction.

Further contraction of the saddle area of the cast after application of beeswax was not expected. However, EARNSHAW (9) had noted that where an investment model is allowed to stand overnight a slight dimensional contraction occured, and this could account for the further dimensional contraction recorded after application of beeswax.

The greatest dimensional change however, was observed during the casting procedure itself being of the level of 0.94 per cent shrinkage. It has been indicated previously that contraction of metals does occur during cooling and the techniques used in casting are designed to compensate for this. The shrinkage recorded in this study is lower however than that recorded by Earnshaw[8] who showed an actual casting shrinkage for high fusing cobalt-chromium alloys as being between 2.13 and 2.33 per cent. Assuming that the recognized technical procedures had been followed for each study,it is likely that the lower value recorded in the present investigation was due to greater compensatory thermal expansion of the investment mould.

Further consideration of the results presented demonstrate that casting shrinkage occured not only relative to the master cast but also relative to the refractory cast after beeswax application, the latter difference being accounted for entirely by metallic contraction. It would be expected therefore that shrinkage of the framework would also occur relative to any wax pattern which was adapted to the beeswaxed refractory cast.

When measurements were compared between frameworks cast in new metal and those cast in used metal, there was found to be no significant dimensional change, which would suggest as far as dimensional accuracy is concerned, that either new or used metal could be used in the casting of cobalt-chromium alloy.

On inspection of the castings however, it was noticed that nodular excrescences were present on all framework cast in used metal whilst being absent on frameworks cast in new metal.
The location of these defects were variable, some being adjacent to the sprues, some on the casting outer surface, but never occurring on the fitting surface. This was an incidental finding during the study and clearly merits further investigation.

Conclusions

(1). Dimensional changes occur at each stage during the production of a denture casting. When comparing the cast metal framework with the master cast, a mean casting shrinkage of 0.94 per cent is evident. In addition contraction occurs between the stone master cast and the refractory cast before beeswaxing, and between the refractory cast before and after the adsorption of beeswax. Casting shrinkage is also evident when comparing the wax pattern to the resultant metal framework.

(2). There is no significant difference in dimension between casting frameworks obtained from either new metal ingots or reused metal.

(3). Nodular defects are present on all frameworks cast in used metal whilst being absent on frameworks cast in new metal.

Summary

The actual casting shrinkage of the cobalt-chromium alloy has been determined by measuring the dimensional changes at every stage during the technical procedure involved in the production of a denture casting. A mean casting shrinkage of 0.94 per cent was obtained when comparing the cast metal framework with the master cast. There was no significant differences in dimensional changes when comparing the new metal and the reused metal frameworks.

REFERENCES

1. ASGAR, K. and PEYTON, F.A. (1961)
Effect of casting conditions on some mechanical properties of cobalt-base alloys.
J. Dent. Res. 40 : 73.

2. BATES, J.F. (1963)
Clinical and laboratory studies on the behaviour of cobalt chromium alloys as partial denture materials.
D.D.S. Thesis : Victoria University of Manchester.

3. CUNNINGHAM, D.M. (1973)
Comparison of base metal alloys and type IV gold alloys for removable partial denture frameworks.
Dent. Clin. N. Am., 17 ::719.

4. DELORO STELLITE LTD. (1955)
Physical and mechanical properties of Stellite.
Publication S.P.13, Birmingham.

5. DOOTZ, E.R., CRAIG, R.G. and PEYTON, F.A. (1965)
Influence of investments and duplicating procedures on the accuracy of partial denture castings.
J. Prost. Dent. 15 : 679.

6. EARNSHAW, R. (1957)
The casting shrinkage of some dental cobalt chromium alloys and its compensation by investment expansion.
Ph.D. Thesis : Victoria University of Manchester.

7. EARNSHAW, R. (1958)
The casting shrinkage of cobalt-chromium alloys.
Aust. Dent. J. 3 : 159.

8. EARNSHAW, R. (1960 a)
Further measurements of the casting shrinkage of dental cobalt-chromium alloys.
Brit. Dent. J. 109 : 238.

9. EARNSHAW, R. (1960 b)
Investments for casting cobalt-chromium alloys.
Brit. Dent. J. 108 : 389.

10. FUSAYAMA, T. (1959)
Factors and technique of precision casting. Part II
J. Prost. Dent. 9 : 486.

11. HERBERT, W.E. and THOMPSON, A.R.F. (1934)
A practical comparison of modern gold inlay techniques.
Brit. Dent. J. 57 : 184.

12. LIDDELOW, K.P. (1950)
An experimental investigation into investment materials suitable for use when casting high fusing base metal alloys.
Dent. Rec. 70 : 134.

13. MASAKA, N. (1970)
Studies on casting accuracy of one piece cast fixed bridges.
Shikwa Gakuho 70 : 1.

14. OSBORNE, J. and WILSON, H.J. (1970)
Dental Mechanics for Students.
6th edition, Staples Press, London.

15. PAFFENBARGER, G.C. (1947)
Shrinkage during casting of gold and gold alloys.
J. Am. Dent. Assoc. 34 : 223.

16. PAFFENBARGER, G.C., CAUL, H.J. and DICKSON, G. (1943)
Base metal alloys for oral restorations.
J. Am. Dent. Assoc. 30 : 852.

17. PULSKAMP, F.E. (1979)
A comparison of the casting accuracy of base metal and gold alloys.
J. Prost. Dent. 41 : 272.

18. ROYDHOUSE, R.H. and SKINNER, E.W. (1961)
The accuracy of large casting.
J. Dent. Res. 40 : 1057.

19. SOEBIJANTORO, B. (1981)
Some factors affecting the accuracy of denture castings.
M.Sc. Thesis : Victoria University of Manchester.

20. TAYLOR, D.F., LEIBFRITZ, W.A. and ADLER, A.G. (1958)
Physical properties of chromium-cobalt dental alloys.
J. Am. Dent. Assoc. 56 : 343.