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The effects of casting techniques on the mechanical properties of a dental cobalt-chromium alloy

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Tensile test pieces were cast by four selected sprueing techniques and studied for density and tensile properties. One of the sprueing systems referred to as horizontal twin feed produced the most consistent and the highest values for mechanical properties. This same series exhibited the lowest percentage elongation and the highest density.

1. Introduction

Since the introduction of cobalt-chromium alloys into dentistry by Erdle and Prange [1], numerous research papers have been published relating the microstructure of the alloys to their mechanical properties. Individual investigators have used different tensile test pieces and sprueing systems for assessing the tensile properties of the alloys used.

Earnshaw [2] adopted the Hounsfield No. 12 test piece and placed five wax patterns in a vertical cluster with individual sprues feeding each end of the pattern, the minor individual sprues radiating from a vertical central main feed (Fig. 1a). Harcourt [3] used the B.S. 3366 (1961) test piece with three patterns to each casting. The orientation of the patterns and sprueing system was similar to that in the Earnshaw technique (Fig. 1b).

Taylor and Sweeney [4] recommended the same procedure as that in American Dental Association Specification No. 14. The test piece patterns, two, three or four in number, to be arranged symmetrically in a vertical plane around a central main feed with individual sprues to one end of each pattern (Fig. 1c), whereas Asgar *et al* [5] used the A.D.A. Specification No. 14 tensile test piece with a modified sprue system. Single patterns were placed on a horizontal plane with individual sprues attached to each end of the pattern (Fig. 1d).

Direct comparison of the results obtained by these researchers is almost impossible with so many variables in pattern dimensions and sprueing systems. It is apparent that if valid comparisons are to be made, the tensile pattern, the sprueing system, and casting technique should be standardized. The "Draft British Standard Specification for Dental Base Metal Casting Alloys Part 1: Denture Base Alloys"* attempts to resolve this situation by recommending a specific tensile piece and sprueing pattern.

Paddon *et al* [6] made a preliminary investiga-

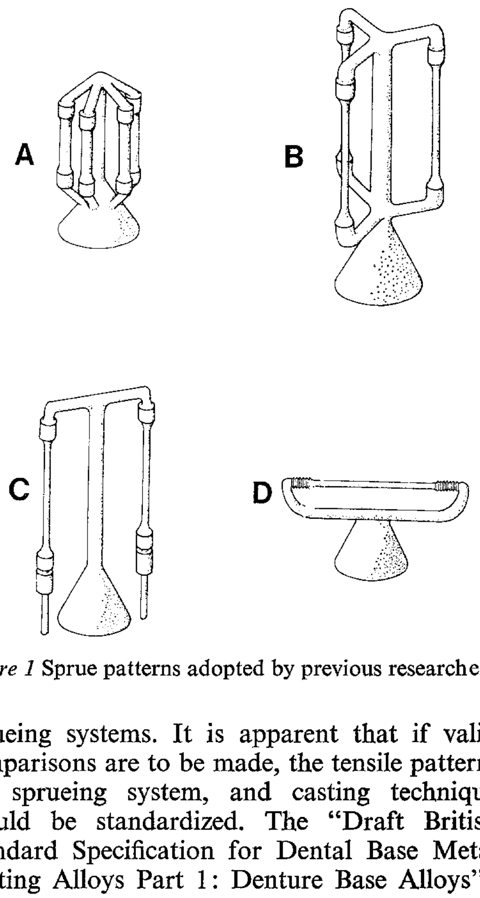

Figure 1 Sprue patterns adopted by previous researchers

*British Standards Institution. Document 73/61303 DC.

tion of the relative merits of different sprueing systems using a recommended B.S.I. 18 test piece when evaluating methods of measuring elongation. Their findings suggested that tensile specimens cast with the patterns placed horizontal to the main sprue feed produce specimens that exhibit increased percentage elongation values and decreased scatter in tensile property values. However, no detailed information has been published at this time to verify these particular assertions.

The objectives of this paper are to: (i) establish if one sprueing system exhibited improved mechanical properties; (ii) ascertain if a correlation exists between recorded density values and mechanical properties.

2. Materials and methods

Four sprueing patterns were selected for this project as illustrated in Fig. 2, with H.T.F. representing the pattern recommended [6]. The wax patterns were prepared by injecting molten wax under pressure into a split brass mould. Twelve tensile patterns (B.S.I. 18, 3 mm diameter round test bar) were produced for each of the four sprueing techniques. To standardize the investing and casting procedure, all the patterns were invested in a phosphate-bonded investment,* and treated to the same heating cycle, i.e. 0 to 1000°C over a period of 3 h, and heat-soaked at 1000°C for 20 min.

The alloy (CROFORM 38†) was cast in a centrifugal induction casting machine‡ at constant temperature. All the castings were allowed to bench cool for a minimum period of 40 min prior to devesting and sand-blasting. The majority of the cast specimens were clean and free from nodules due to careful spatulation of the investment material under vacuum. However, in the few instances where small nodules did occur, these were removed with small carbide stones.

The direct recording of the mechanical properties was made possible by the use of a strain gauge extensometer coupled to a servo chart drive system of an Instron Tensometer. Prior to each series of tensile tests, the strain gauge was calibrated for magnification factor by use of a specimen jig and bench micrometer. Due to the design of the strain gauge used in these experiments, the maximum possible gauge length was limited to 10 mm of the total 15 mm. The mean diameter of each test bar was calculated by recording three measurements along the gauge length and a further three with the test bar rotated axially through 90°.

Density determinations of two flat hot-rolled ingots, together with the tensile specimens, were

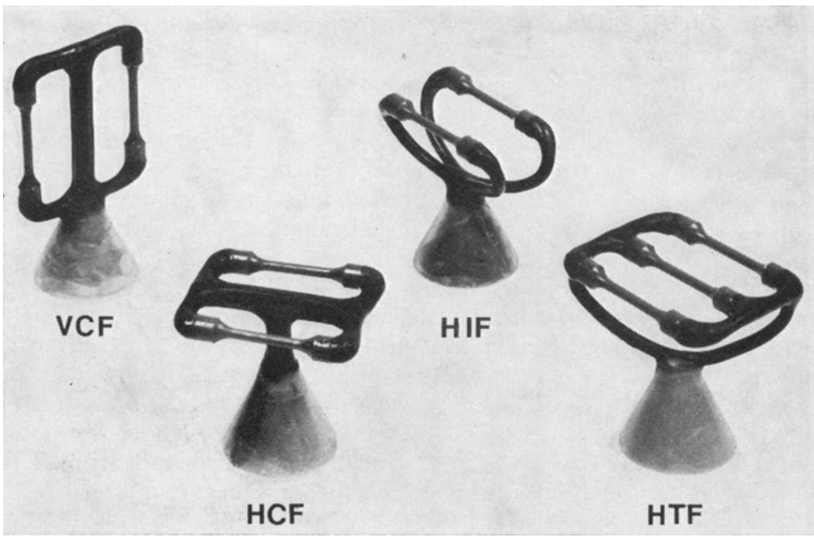

Figure 2 Sprue patterns selected for assessment of density values and mechanical properties.

*Multivest, Ransome & Randolph.
†Williams Inductocast, Williams Gold Refining Co, Inc, Buffalo, N.Y.
‡Davis Schottlander & Davis Ltd, London.

TABLE I Summary of mean values, standard deviations and coefficients of variation of the specified mechanical properties for series 1 to 4

Mechanical properties	Series 1 V.C.F. kg cm²	Series 2 H.C.F. kg cm²	Series 3 H.I.F. kg cm²	Series 4 H.T.F. kg cm²
Proportional limit				
Mean values	4264	3326	3586	3867
$\sigma \pm$	621	351	247	369
Coefficient of variation (%)	14.5	10.5	6.9	9.5
0.1% proof stress				
Mean values	5010	4345	4586	5463
$\sigma \pm$	451	378	287	178
Coefficient of variation (%)	9	8.7	6.2	3.2
0.2% proof stress				
Mean values	5291	4706	4928	5779
$\sigma \pm$	421	456	277	162
Coefficient of variation (%)	7.9	9.6	5.6	2.8
Ultimate tensile stress				
Mean values	7649	6698	7600	8108
$\sigma \pm$	436	366	547	370
Coefficient of variation (%)	5.7	5.5	7.2	4.5
Percentage elongation				
Mean values	5.8	6.6	7.7	5.6
$\sigma \pm$	2.37	1.90	1.92	1.16
Coefficient of variation (%)	41	29	25	20.5

measured using distilled water as the immersion medium. Results were corrected for variations in temperature of the water.

The following data for mechanical properties were recorded for each test series:
(1) limit of proportionality;
(2) 0.1% proof stress;
(3) 0.2% proof stress;
(4) ultimate tensile strength;
(5) % elongation.

3. Results

Analysis of the comparative mean values for mechanical properties of each series revealed that the sprueing system has a significant effect on the final tensile properties of the test piece. The results of these tests are shown in Table I.

3.1. Limit of proportionality

Owing to the difficulty in accurately measuring values within ± 5% limits, the final results for this particular physical property are of value only in broad comparative terms.

Series V.C.F. exhibited the highest mean value and also the highest standard deviation with a coefficient of variation in excess of 14%. Series H.T.F. was ranked second on mean values, and the second lowest in terms of standard deviation. The most consistent results for proportional limits were obtained for series H.I.F. with a coefficient of variation approximating to 7%. However, the mean value for this series was ranked third behind series V.C.F. and H.T.F. It would, therefore, be a most difficult task to recommend any specific sprue system from these results alone.

3.2. Proof stress 0.1 and 0.2%

The proof stress is a more accurately determined measure of the yield stress of an alloy and, as such, is generally accepted in preference to values recorded for the limit of proportionality. Of the four series analysed for mean proof stress values, those recorded for series H.T.F. were 9 to 25% higher than for any other series in relation to both 0.1 and 0.2% proof stress.

Equally important in assessing the significance of these results, the most consistent set of values with the lowest standard deviation was obtained for series H.T.F. The respective coefficients of variation for 0.1 and 0.2% proof stress were lower than for any other series.

3.3. Ultimate tensile strength

The mean values for this tensile property followed a similar pattern to those exhibited for proof stress with series H.T.F. having the highest mean value and the lowest standard deviation. Series V.C.F. and H.I.F. had mean values of 6% lower than series H.T.F. in conjunction with increased variability values.

3.4. Percentage elongation

The highest mean value obtained for percentage elongation was that of series H.I.F. and the lowest in series H.T.F. which also gave the most consistent results with lowest standard deviation.

To test further the assertions drawn from the tensile results in relation to the most suitable sprue system individual results were subjected to further analysis. Any individual result that exhibited a value greater than $\pm 2\sigma$ from the original mean value was omitted and new mean values assessed. The revised table of results (Table II) confirms series H.T.F. as the most consistent series overall.

In no instance did more than one individual result need to be omitted for any tensile property in any series.

3.5. Density determinations

The results of six separate determinations on the two flat rolled ingots indicated that the mean values for these two were 8.40 and 8.39 with respective standard deviations of $\pm$ 0.0151 and 0.0085. It was assumed that these were base-lined determinations since the hot-rolling would eliminate any porosity.

The mean values obtained for the different sprueing systems (Table III) show that the highest mean density was exhibited in the H.T.F. series with the lowest in the H.I.F. series. These results suggest that the method of sprueing has a limited effect on the density of the tensile specimens.

TABLE II Revised mean values, standard deviations and coefficients of variation, determined from specimens not in excess of $\pm 2\sigma$ from original mean values

Mechanical properties	Series 1 V.C.F. kg cm^2	Series 2 H.C.F. kg cm^2	Series 3 H.I.F. kg cm^2	Series 4 H.T.F. kg cm^2
Proportional limit				
Mean values	4129	3399	3538	3792
$\sigma \pm$	376	257	192	273
Coefficient of variation (%)	9.1	7.6	5.4	7.2
0.1% proof stress				
Mean values	4896	4266	4647	O.VI*
$\sigma \pm$	228	274	202	
Coefficient of variation (%)	4.7	6.4	4.3	
0.2% proof stress				
Mean values	5189	4592	4982	O.V.
$\sigma \pm$	241	242	211	
Coefficient of variation (%)	4.6	5.3	4.2	
Ultimate tensile stress				
Mean values	O.V.	O.V.	7711	O.V.
$\sigma \pm$			409	
Coefficient of variation (%)			5.3	
Percentage elongation				
Mean values	O.V.	O.V.	8.0	O.V.
$\sigma \pm$			1.51	
Coefficient of variation (%)			19	

*O.V. original mean value – signifies that all results fall within the specified parameters of $\pm 2\sigma$ from original mean value.

TABLE III Density values for the sprue patterns

Series 1 V.C.F. Specimen no.	Density	Series 2 H.C.F. Specimen no.	Density	Series 3 H.I.F. Specimen no.	Density	Series 4 H.T.F. Specimen no.	Density
1	8.38	1	8.41	1	8.34	1	8.43
2	8.46	2	8.32	2	8.39	2	8.45
3	8.45	3	8.41	3	8.38	3	8.30
4	8.40	4	8.43	4	8.41	4	8.48
5	8.47	5	8.46	5	8.40	5	8.40
6	8.39	6	8.37	6	8.35	6	8.46
7	8.51	7	8.40	7	8.41	7	8.50
8	8.48	8	8.38	8	8.42	8	8.47
9	8.43	9	8.25	9	8.35	9	8.49
10	8.43	10	8.38	10	8.34	10	8.41
11	8.37	11	8.50	11	8.38	11	8.52
12	8.43	12	8.41	12	8.42	12	8.54
Mean value	8.43	Mean value	8.39	Mean value	8.38	Mean value	8.45
σ	0.042	σ	0.064	σ	0.031	σ	0.0643
Coefficient of variation (%)	0.49	Coefficient of variation (%)	0.76	Coefficient of variation (%)	0.37	Coefficient of variation (%)	0.76

4. Discussion

The sprue system referred to as Horizontal Twin Feed (H.T.F.) provided the most consistent results for those tensile properties which are of real significance. A direct relationship between the mechanical properties of ultimate tensile strength and proof stress and an inverse relationship with elongation have been established and this is consistent with the mechanical properties in many alloy systems.

The greatest mean values were obtained for proof stress and ultimate tensile stress in these specimens cast by the Horizontal Twin Feed system and inversely the lowest mean elongation value. However, as the final value is above the limit set by the specifications, the fact that the coefficient of variation for this series was the lowest of those tested is of importance. The level of consistency in results for all tensile properties obtained for this sprueing technique confirms the horizontal twin feed sprue system as the recommended method for tensile patterns.

5. Conclusions

The sprueing technique used for casting tensile specimens has a significant effect on the mechanical properties of a cobalt-chromium alloy. It has been shown that of the four methods studied in this project, the sprueing technique referred to as horizontal twin feed exhibited the highest mean values for all tensile properties and the lowest percentage elongation.

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