Dimensional Change in Dental Ni–Cu–Mn-based Alloys

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ABSTRACT

Dimensional change in experimental Ni–Cu–Mn-based alloys was examined measuring a clearance value between cast crown and steel die. The magnitude of shrinkage value ranged from −2.08 to −2.40% for the alloys tested. Dimensional change values measured and calculated were in a good agreement. Negative and positive values were estimated for the alloys cast into one phosphate-bonded investment mould, and positive value was obtained when 5 weight percent of aluminum to the parent 20Ni–40Cu–40Mn and 40Ni–30Cu–30Mn ternary alloys was added. This study clarified that 20Ni–40Cu–35Mn–5Al and 38Ni–28.5Cu–28.5Mn–5Al alloys exhibited a positive value by selecting phosphate-bonded investment with appropriate expansion value (total expansion = 2.2%) to compensate metal shrinkage values after melting and subsequently cooling to room temperature.

INTRODUCTION

The magnitude of shrinkage after casting was measured for dental application to cast crown. The 30 nickel (Ni)-30 copper (Cu)-40 manganese (Mn)-based alloys (wt%) including 5, or 10 wt% aluminum (Al) to the parent alloy exhibited a decreased percentage of dendrite structure[1]. The accuracy of dimensional changes in relation to cast shrinkage in their alloys was close to the positive values of commercial Ni-based alloys[1]. The marginal accuracy as a dimensional change to the steel die after casting has not been evaluated for high Ni-containing-Cu-Mn alloys. This study clarified the measured value of experimental Ni–Cu–Mn–Al-based alloy systems with different magnitudes of metal shrinkage (S) value within dental investment mould.

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MATERIALS AND METHODS

Experimental alloy systems were indicated in Table 1: A1, 20Ni–40Cu–40Mn (970°C as liquidus fusion temperature); A2, 30Ni–30Cu–40Mn (1000°C); A3, 30Ni–40Cu–30Mn (1050°C); A4, 40Ni–30Cu–30Mn (1075°C); A5, 50Ni–30Cu–20Mn (1160°C); A1A, 20Ni–40Cu–35Mn–5Al (985°C); A4A, 38Ni–28.5Cu–28.5Mn–5Al (1060°C); A5A, 47.5Ni–28.5Cu–19Mn–5Al (1140°C). As a control alloy, 2 commercial alloys as 84Ni–9Cr alloy including manganese and molybdenum (NCR; Shofu Inc, Kyoto, 1310°C) and 32Ni–23Cu–25Mn–10Cr–7Ge alloy including silicon (NCM; Sankin Ind, Tokyo, 965°C) were used. Ni–Cu–Mn-based alloys were formulated by vacuum melting as described in the previous studies[1–3].

Casting procedures of the alloys tested were carried out using centrifugal casting machine. Phosphate-bonded investment mould was used for experimental Ni–Cu–Mn-

Table 1 Materials developed and tested in this study. See text for key.

Code	Alloy
A1	20Ni–40Cu–40Mn
A2	30Ni–30Cu–40Mn
A3	30Ni–40Cu–30Mn
A4	40Ni–30Cu–30Mn
A5	50Ni–30Cu–20Mn
A1A	20Ni–40Cu–35Mn–5Al
A4A	38Ni–28.5Cu–28.5Mn–5Al
A5A	47.5Ni–28.5Cu–19Mn–5Al
NCR	84Ni–9Cr*
NCM	32Ni–23Cu–25Mn–10Cr–7Ge*

* The other elements (not described).

based alloys and commercial alloys NCR and NCM alloys (Univest Nonprecious investment, Shofu Inc (UN); setting expansion=1.0% (SE) and thermal expansion=1.2% (TE); DT-50, Shimadzu Co, Kyoto).

S values of Ni-based alloys were considered as thermal expansion values until the melting temperatures of Ni-based alloys (Rigaku Thermoflex, Tokyo), similar to the previous reports[4,5]. Dimensional change between the die and metal castings was measured to compare with a calculated value[4].

The dimensional change values of metal crowns were examined with sharp light through a magnifying lens (4×) and calculated from the clearance value[6]. The value for each was evaluated by measuring the clearance between the magnitude of the metal crown and the shoulder of the steel die in applying 1.0 kg load to the superior surface of cast crown (Fig. 1). The taper was expressed by H/(B−A) (H; 9.92 mm, A; 8.90 mm, B; 9.89 mm), and the marginal value as a dimensional change was calculated as [clearance/(taper×B)]×100(%). The negative value was recorded for the contracted crown, and the positive value for the expanded crown was obtained by removing the dotted portion on steel die.

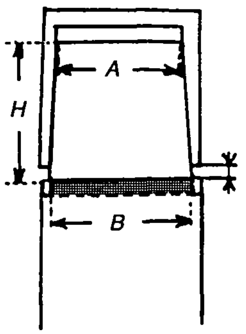

Fig. 1 Metal crown model die for clearance measurement (H, A, and B). Cross section.

RESULTS

Table 2 indicates S value in Ni-based alloys, representing that Ni–Cu–Mn-based alloys had −2.08 to −2.40% and commercial NCR and NCM had −2.30 and −2.10%. Table 3 indicates the dimensional change values that are different among Ni–Cu–Mn-based alloys, compared with large (positive) values (0.24 and 0.30%) in commercial NCR and NCM alloys. The small difference of their values was between measured and calculated values in experimental Ni-based alloy systems (Table 3). One investment mould (UN) was used, so the variable to affect the accuracy of cast crown was only S value of Ni-based alloys, since the main factors considered were combined expansion (SE and TE) and S values[4].

Table 2 Cast shrinkage (S) values in 10 Ni-based alloys investigated. For code and chemical composition, see text. Sample size=7.

Code	S (%)
A1	−2.18
A2	−2.20
A3	−2.30
A4	−2.35
A5	−2.40
A1A	−2.08
A4A	−2.10
A5A	−2.25
NCR	−2.30
NCM	−2.10

Table 3 Measured and calculated accuracy values as the dimensional change in 8 experimental Ni–Cu–Mn-based alloys and 2 commercial alloys NCR and NCM. UN investment mould was used. See text for key. Sample size=7.

Code	Dimensional change	
	Measured	Calculated*
A1	−0.04 (0.01)	−0.02
A2	+0.00 (0.05)	0.00
A3	−0.12 (0.01)	−0.10
A4	−0.20 (0.06)	−0.15
A5	−0.20 (0.05)	−0.20
A1A	+0.15 (0.01)	+0.12
A4A	+0.12 (0.02)	+0.10
A5A	−0.09 (0.02)	−0.05
NCR	+0.30 (0.10)	+0.35
NCM	+0.24 (0.08)	+0.20

* Calculated by S and combined expansion values.

DISCUSSION

This study was to improve the accuracy of dimensional change between metal crown and the steel die. There was no significant difference between measured and calculated dimensional change values ($p>0.05$). New Ni–Cu–Mn–Al-based alloy systems designated for cast crown exibited smaller value (positive), as compared with commercial Ni-based alloys. Profiles (geometry of finishing lines) of anterior crown were evaluated to determine marginal adaptation[7−9]. In the die with simple geometry, the estimate of dimensional change value is done by the combined value of SE and TE value (positive) and S values (negative)[6−10]. For NCM alloy the value recorded larger value (positive) because of combined expansion (2.2%). The value of small metal castings was influenced by S and combined expansion values[4,5]. The value was modified by combined SE and TE values of the investment used as the mould, or S value of Ni–Cu–Mn-based alloys (Tables 2, 3). The difference between dimensional change values was minimal, and known S value exhibited almost exact dimensional change value of Ni-based alloys (Table 3). S value was estimated from the expansive value of Ni-based alloys during heating from the solid state, and thus the accuracy of value of cast metal crown changed only by S value because of constant combined value of investment mould. S values in A1A and A4A alloys (−2.08 and −2.10%) exhibited the improved accuracy of cast metal crown (positive) (Tables 2, 3).

Ni–Cr based alloys showed better fit similar to high-palladium alloy and gold alloys[10,11]. Marginal clearance as a dimensional change is to consider S value and combined SE and TE value for small castings[4], and the clearance value was needed to be 5 to 30 μm considering the layer of cement between steel die and cast crown. The expanded crown (size of B in Fig. 1; 9.89 mm) needed the expansion value of +0.1 to +0.6% as the clearance. The alloys with appropriate dimensional change value (positive) were A1A and A4A of experimental alloy systems investigated (Table 1).

SUMMARY

Only S value was critical for ensuring the accuracy as the dimensional change value at constant combined value. With the addition of aluminum to the parent Ni–Cu–Mn-based alloy systems, S value was controlled for each of parent ones. This study summarized that the aluminum addition improved effectively the fittness as the dimensional change in Ni–Cu–Mn-based ones.

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