The castability of ternary Ni–Cu–Mn alloys for crown and bridge applications

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An evaluation of the castability of ternary Ni–Cu–Mn alloys was made for crown and bridge applications. The castability values were compared with those of commercial nickel-based alloys, and the effect of air-venting on the castability was examined. The result that a significant difference is found between ternary alloys and commercial high-fusing alloy shows that the most castable alloys are the ternary ones. When using air-venting within the investment mould, the ternary alloys had more-complete casting than their values in an investment mould without venting.

1. Introduction

Non-precious nickel-based alloys have recently been introduced to the dental field for use in crown and bridgework as alternatives to gold alloys [1–5]. The non-precious alloys have properties such as higher elasticity and lower cost than gold alloys [1, 3, 4]. The alloys have the advantages of being harder and stronger than the commercial gold alloys used for ease of manipulation, but their casting shrinkage and final polishing should be considered [6, 7]. In dental casting the substitute base-metal alloys occasionally gave difficulties because of casting defects and lower castability [8–10].

This study on the castability of non-precious base-metal alloys was made based on the following points. Venting and a proper sprue diameter improved the alloy castability [11], and the particular combination of alloy and investment was important to the castability [1]. The base-metal alloys were used with a phosphate-bonded investment which has no gypsum, because of the high fusing temperature [12, 13]. In addition, the increase in the mould and casting temperatures gave a higher castability [1, 11]. It is, however, considered that the higher temperature of the mould and casting could affect some properties of the base-metal alloys, because trace elements in the alloys would be lost. The ringless investment technique, which was used to maximize the escape of trapped gases during casting, was used in casting the base-metal alloys [7, 14]. In order to cast the base-metal alloys it may be necessary to consider the effect of the casting conditions on the castability of the base-metal alloys. The purpose of this study was to evaluate the castability of experimental ternary Ni–Cu–Mn alloys as a non-precious base-metal alloy and to compare the castability of experimental alloys with those of commercial nickel-based alloys. In addition, venting was used for the evaluation of castability in the base-metal alloys investigated.

2. Materials and methods

The following experimental ternary Ni–Cu–Mn alloys [5] and commercial nickel-based alloys were used: 20 wt % Ni–40 wt % Cu–40 wt % Mn (alloy 1, 970° C liquidus melting temperature), 30Ni–30Cu–40Mn (alloy 2, 1000° C), 30Ni–40Cu–30Mn (alloy 3, 1050° C), 40Ni–30Cu–30Mn (alloy 4, 1075° C) and 50Ni–30Cu–20Mn (alloy 5, 1160° C) for experimental alloys, and 84Ni–9Cr alloy (Summalloy Nickel soft, Shofu Inc., Kyoto, Japan; Sm, 1310° C) and 32Ni–23Cu–25Mn–10Cr–7Ge alloy (Fittloy 50 Type I, Sankin Ind., Tokyo, Japan; Ft, 965°C) for commercial alloys. The fine additive elements in commercial alloys detected by X-ray analysis included molybdenum, silicon, iron and cobalt [15–17].

The machined metallic die and the investment moulds for the wax patterns are shown in Fig. 1. The investment moulds in Figs 1b and c were made using impression material taken from the metallic die. The mould shown in Fig. 1c had a hole (made using a Co–Cr wire of diameter 2.3 mm when the impression was taken) along the longitudinal direction at its centre to use for air-venting. The wax patterns were prepared by rotating wax of different diameter along the spiral in the investment moulds (Figs 1b and c), and three kinds of wax pattern (Figs 2a to c) were obtained. The wax pattern was sprued to its wax crucible as shown in Fig. 2, and the length of the sprue in Figs 2a and b was kept constant at 3 mm. The diameters of sprue used were 1.5, 1.0 and 0.7 mm for each wax pattern. In Figs 2a and b (the wax patterns with spiral diameters of 1.5, 1.0 and 0.7 mm) the same diameter of sprue as the patterns was used. In the pattern of Fig. 2c four different combinations (shown in Table I) were used. All wax patterns attached to the investment moulds were invested with the investment used for each alloy: Univest non-precious investment (brand name) for the ternary Ni–Cu–Mn alloys (Shofu Inc, Kyoto, Japan), Summavest investment

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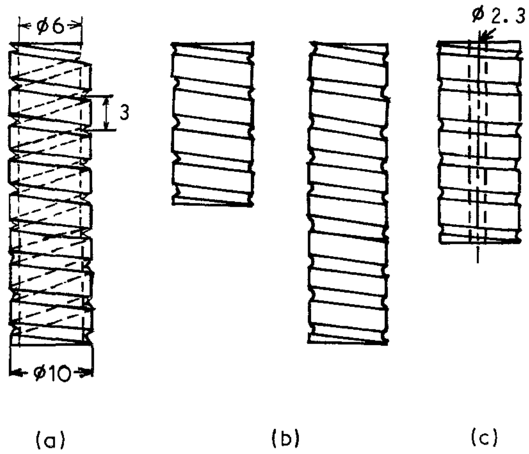

Figure 1 Moulds for wax patterns. (a) Metallic die; (b) investment moulds with four and eight rotations obtained from the impression mould of (a); (c) investment mould with a central hole for air-venting.

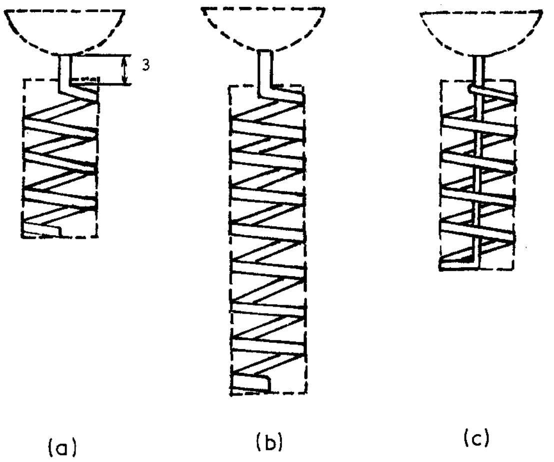

Figure 2 Wax patterns investigated. (a) Four times for spiral rotation; (b) eight times for spiral rotation and (c) five times for spiral rotation which starts from the bottom of the investment mould when the long sprue canal is attached to the bottom.

(brand name) for the commercial 84Ni–9Cr alloy (Shofu Inc., Kyoto, Japan) and Fittment investment (brand name) for 32Ni–23Cu–25Mn–10Cr–7Ge alloy (Sankin Ind., Tokyo, Japan). Two stainless steel rings (diameter 36 mm × height 55 mm, and diameter 36 mm × height 40 mm) were used for the casting, according to the length of the wax pattern. The investments were heated to 750° C (for the first two) and 700° C (for the last one) and held at this temperature for 30 min before the casting was made. The alloys were melted by high-frequency fusion with a flow of argon gas, and were cast with centrifugal casting (Castron-8, Yoshida Co., Tokyo, Japan).

The percentage castability value obtained from the wax patterns was evaluated from the change of the rotation in the cast with initial rotations (four, five and eight times) [2, 18]. The complete cast was defined to be 100%, and the weight of alloys melted was about 20 g for all patterns. Therefore, the castibility of the alloys used was calculated in a similar casting to assess the different kinds of alloys. In addition, the effect of air-venting while casting on the castability was investigated, because the base-metal alloys were effectively cast with a hole for an air-vent to enable gases in the investment to escape [19, 20]. Air-venting was used to cool the cast through the hole in the investment for the investment mould shown in Fig. 1c, and comparison was made with the casting using an investment mould without the hole. Optical microscopy of the alloys tested was used to clarify the differences in structures among the alloys and commercial alloys, both with and without air-venting. Etched structures were obtained by Nital etchant [5].

3. Results

The castability of commercial alloy Ft decreased with decreasing diameter of the wax pattern (Fig. 3, rotation is four times), reaching a value about 80% As indicated in Table I (air-venting not used and rotation was four times) the values for commercial alloy Ft became larger than those for commercial alloy Sm when diameters of 1.0 and 0.7 mm were used for the wax patterns. In particular, the values for the latter alloy were half those for the former. In Table II (air-venting not used, and the rotation for the castability was four times) the castabilities in the wax pattern in Fig. 2c are given. The smaller diameter of the sprue portion gave a lower value for the castability compared with that for the larger diameter of the sprue canal in the wax pattern.

The effect of air-venting on the castability is shown in Fig. 4 and Table III. In Fig. 4 (rotation four times) the castability of commercial alloy Sm decreased with air-venting, whereas commercial alloy Ft had a larger castability when air-venting was used. In Table III (commercial alloy Sm, rotation four times) the use of air-venting was not effective for castability when three kinds of wax patterns of different diameters of 0.7, 1.0 and 1.5 mm were used.

The castibility of ternary Ni–Cu–Mn alloys is shown in Fig. 5. The castability increased for the ternary alloys compared with the commercial alloy Sm, and complete casting was found for a spiral of four rotations in the castability evaluation except for 50Ni–30Cu–20Mn (alloy 5, about 90%) and commercial alloy Sm. Table IV (the castability values in ternary alloys when air-venting was used) indicates

TABLE I Castability measurements (%) for commercial nickel-based alloys (Ft, 32Ni–23Cu–25Mn–10Cr–7Ge; Sm, 84Ni–9Cr)

Alloy	Diameter	
	0.7 mm	1.0 mm
Ft	80.5 ± 4.5	90.4 ± 4.4
Sm	35.2 ± 4.0	44.0 ± 5.0

TABLE II Castability values in a commercial nickel-based alloy Ft

Diameter (mm)		Castability (%)
ds	dc	
0.7	0.7	66.4 ± 1.5
0 7	1.0	55.4 ± 7.5
1.0	0.7	78.5 ± 7.2
1.0	1.0	100

ds, Diameter in sprue canal; dc, diameter in spiral portion.

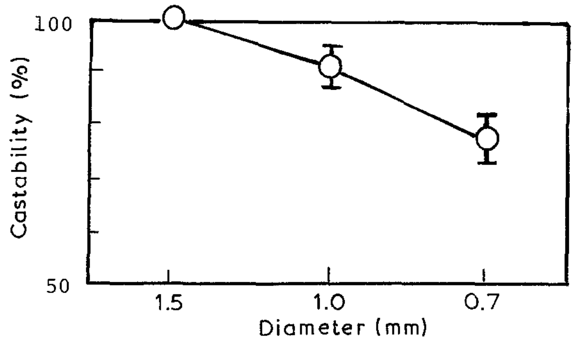

Figure 3 Castability values for commercial alloy Ft (four times rotation and air-venting).

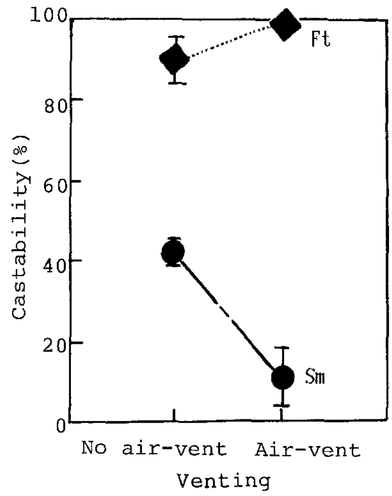

Figure 4 Castability change (rotation four times and spiral diameter of 1.0 mm) when air-venting was used in commercial nickel-based alloys Ft and Sm.

almost complete casting and the castability had a value of more than about 95%. The microstructures in Fig. 6 were dendrite structure (a and b) and cellular structure (c to e) according to [21, 22]. In commercial alloys (f and g) dendrite structures in g were smaller than those in f. When using air-venting during casting (Figs 7a and b), the microstructures in the commercial alloys changed to both the structures with a small size in Fig. 7a and the cellular structure in Fig. 7b.

4. Discussion

The shape and dimensions (diameter and rotation) of the wax pattern gave a quantitative evaluation of castability of the nickel-based alloys tested. The evaluation showed the difference among the alloys and the difference of the effect of air-venting on castability (Table III and Fig. 4). Maximization of escaped gases during casting was important in casting nickel-based alloys [7]. The ringless investment technique and vacuum mixing of the investment were used for the casting. In this study the method to enable trapped gases to escape during casting was to use air-venting within the investment mould (Fig. 1). In high-fusing alloy (Sm) the castability decreased compared with that in commercial low-fusing alloy (Ft). In fact, the castability of alloys 4 and 5, which had higher melting temperatures than the others, was less than in the other alloys 1, 2 and 3 (Fig. 5). This means that the cooling effect due to air-venting was remarkable for the high-fusing alloy, and the results indicate that the microstructures changed to cellular structure with air-venting in nickel-based alloy Sm (Figs 6 and 7). Thus, air-venting could be used for the low-fusing rather than for high-fusing nickel-based alloy. The microstructure when air-venting was used varied more in the high-fusing than in the low-fusing alloys (Fig. 7). In ternary Ni–Cu–Mn alloys the structures were changed to dendrites by adding additive alloy elements to the ternary alloys [23]. The low-fusing alloys could be used by air-venting without less castability, as compared with that in the high-fusing alloy.

At the 95% confidence level there was a significant difference among the casting machines (including the induction unit, resistance unit and vacuum–air pressure unit) and alloys (base-metal alloy, high-fusing noble-metal alloy and type III gold alloy) [4]. The casting machine had a strong effect on the change of castability. In this study the casting conditions were kept constant during casting of the alloys tested. As the investment included various trapped gases, their escape was by a familiar method in removable prosthodontics. Castability is required in order to obtain a crown and bridge by means of the complete filling of

TABLE III Effect of air-venting on the castability (%) in commercial alloy Sm when diameters of 0.7, 1.0 and 1.5 mm were used for the spiral

System	Diameter		
	0.7 mm	1.0 mm	1.5 mm
No air-venting	35.2 ± 4.0	44.0 ± 5.0	55.4 ± 5.5
Air-venting	8.2 ± 3.2	12.0 ± 7.0	20.5 ± 2.2

TABLE IV Castability (%) in ternary alloys when the air-vent was used for four and eight rotations in the spiral portion

Alloy	No of rotations	
	Four	Eight
20Ni–40Cu–40Mn	100	100
30Ni–30Cu–40Mn	100	100
30Ni–40Cu–30Mn	100	100
40Ni–30Cu–30Mn	100	98.5 ± 2.4
50Ni–30Cu–20Mn	98.2 ± 3.2	95.2 ± 5.6

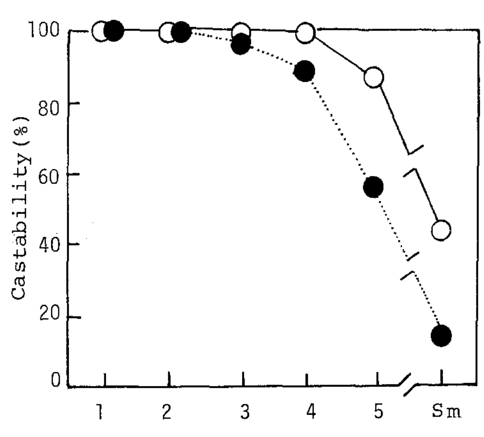

Figure 5 Castability values of ternary Ni–Cu–Mn alloys and commercial alloy Sm for each spiral with (○) four and (●) eight rotations.

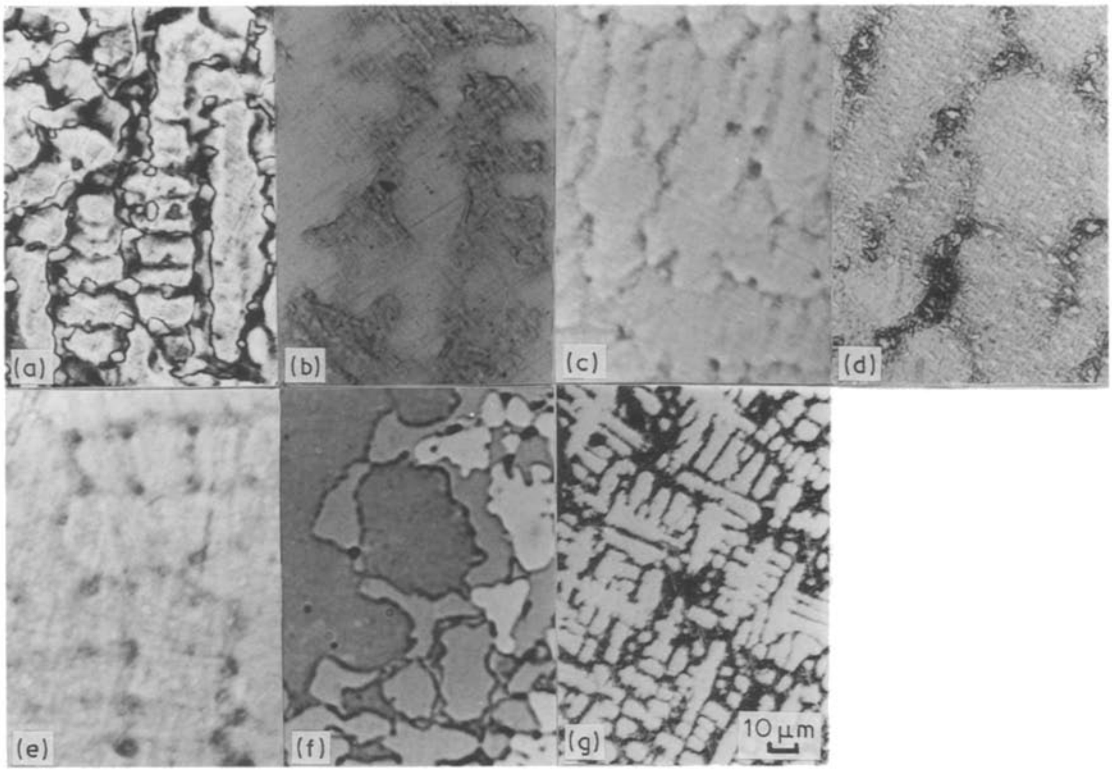

Figure 6 Microstructures in the alloys tested. (a) Alloy 1, (b) alloy 2, (c) alloy 3, (d) alloy 4, (e) alloy 5, (f) Ft and (g) Sm (for key, see text).

the mould cavity, and air-venting was effective for the commercial alloy with low melting temperature, representing a superior castability as shown in Fig. 4.

The castability of low-fusing ternary Ni–Cu–Mn alloy below 1200° C was superior to that of commercial high-fusing nickel-based alloy. The castability of the former was similar to that of the commercial alloy Ft with low fusing temperature (965° C liquidus). The high-fusing nickel-based alloy changed to a cellular structure from a dendrite structure, showing that the structure in the cast was cooled rapidly. Casting of ternary Ni–Cu–Mn alloys could be done with air-venting without a decrease in the castability. In commercial low-fusing alloy the microstructure did not change remarkably when air-venting within the investment mould was used. The results in this study would support the use of air-venting in ternary Ni–Cu–Mn alloys without decreasing the castability during the dental casting of a crown and bridge.

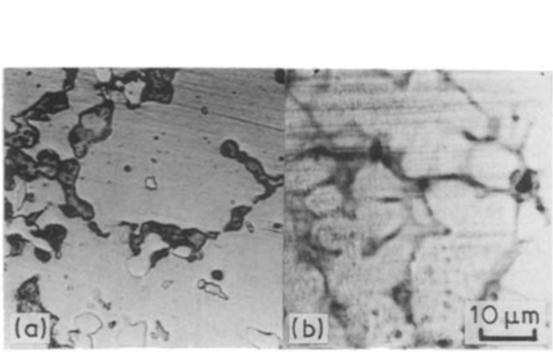

Figure 7 Microstructure changes when air-venting was used. (a) Commercial nickel-based alloy Ft and (b) commercial nickel-based alloy Sm.

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