Dental Ni-based Alloys for Crown and Bridgework: Hardness and Tensile Properties (Classification)

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ABSTRACT

Dental nickel (Ni)-based alloys were examined to clarify the relation between cast structure and hardness number or/and tensile property, and also discussed based on the results of the hardness number and tensile strength and strain. First, the Nibased alloys were classified by both Ni-Cr-based alloys as Ni-Cr-Co, Ni-Cr-Mo, Ni-Cr and Ni-Cr-Cu systems with high melting temperature of more than 1160°C and Ni-Cu-based alloys as Ni-Cu-Mn-Cr-Ge, Ni-Cu-Co and Ni-Cu-Mn systems with low melting temperature of less than 1150°C. Secondly, the Ni-based alloys were specified similar to dental casting gold alloys. Third, the Ni-based alloys were classifed with respect to hardness number and tensile property. The alloys with hardness number of less than 150 (softened condition of gold alloys) and 150 to 220 (age-hardened gold alloy) were defined as the soft type, and the other alloys with more than 220 the hard type. The soft type showed a ductile tensile behaviour with higher tensile strain and the hard type indicated lower tensile strain. The tensile strength in these types ranged approximately from 200 to 700 MPa. The mechanical property was controlled by the additives in the Ni-Cr-or Ni-Cu-based alloys, and their compositions affected the structure parameter as a grain size or cell size.

INTRODUCTION

Dental nickel (Ni)- based alloys were constituted mainly as Ni-Cr-Co-Mo, Ni-Cr, Ni-Co and Ni-Cu alloys based on the chemical compositions[1]. Originally, Ni-Cr-based superalloys[2] were Inconel 1600 (76 Ni-15.8 Cr-7.2 Fe-0.04 C-0.2 Mn-0.2 Si) and Nimonic 80A (75 Ni-19.5 Cr-0.06 C-1.0 Co-1.3 Al-2.5 Ti), and Ni-Cu-based alloys[3] Monel (67 Ni-30 Cu-1 Mn-1.4 Fe-0.1 Si-0.15 C-0.01 S) and S-Monel (63 Ni-30 Cu-0.75 Mn-2 Fe-4 Si-0.1 C-0.015 S). The percentage of the additives means mass fraction in the Ni-based alloys. Thus, the Ni-based superalloys were classified by their compositions, but dental Ni-based alloys had a wide range of hardness number because of cast structure[4,5]. The Ni-based alloy cast structure was composed of a well-developed dendrite structure, and dendrite structure size was influenced by the additives in Ni-based alloys[6-8]. The effect of cast structure on mechanical properties (hardness and tensile properties) was observed for dental Ni-based cast alloys[9]. As a resultant tensile behaviour, tensile fracture at maximum load resulted in applied stress-induced failure either along a grain-boundrary or within the dendrites[4,9,10].

In this study dental Ni-based alloys for crown and bridge application were examined by hardness number and tensile property, and the alloys were classified by the results based on the mechanical properties. The Ni-based alloy microstructure were also observed optically in relation to the mechanical properties.

MATERIALS AND METHODS

Cast specimens tested were sixteen dental commercial Ni-based alloys which were indicated in Table 1. The Ni-based alloys were classified by two groups with high and low melting temperatures based on the chemical compositions as indicated in Table 2. The condition to measure hardness number and tensile properties were as reported previously[9,10]. The test samples (10 pieces) were cast by centrifugal casting with high frequency melting (Cas-

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Table 1 Dental Ni-based alloys tested.

Code	Alloys	Ni	Cr	Co	Cu	Mo	Si	Others
1	Yata Coballium Soft	67	13	—	—	9	—	R
2	Summalloy Nickel	79	13	—	—	5	—	R
3	Tai-crown	77	15	—	—	—	3	R
4	Washi NC-II	62	10	—	15	—	—	Ga (10), R
5	Fitlloy 50 Type I	32	10	—	23	—	—	Mn (25), Ge (7), R
6	Ad-cast	53	5	15	20	—	—	In (6), R
7–1 7–2	Summalloy Nickel Soft	84	9	—	—	—	—	R
8	DRS Soft	96	4	—	—	—	—	—
9	Sancollium S	85	10	—	—	—	—	R
10	Sancollium US	86	11	—	—	—	3	—
11	Alpha-alloy	90	9	—	—	—	1	—
12	Crown 8	86	7	—	4	—	—	R
13	Dent Nickel	63	15	—	—	5	—	Mn (5), R
14	Fitlloy 50 Type II	52	15	—	10	—	—	Mn (20), R
15	Summalloy Titan	28	23	40	—	—	—	Ti (5), R

R; undetected additives

Table 2 Classification of Ni-based alloys due to the compositions.

Alloy systems	Tm (°C)	Code
Ni-Cr-Co	1225–1360	15
Ni-Cr-Mo	1225–1350	1, 2, 13
Ni-Cr	1160–1175	3, 7–1, 7–2, 8 to 11
Ni-Cr-Cu	1180–1335	4, 12
Ni-Cu-Mn (10Cr-7Ge)	965	5
Ni-Cu-Co	1065	6
Ni-Cu-Mn (15 Cr)	1150	14

tron 8, Yoshida, Tokyo). Each investment was Summavest (Shofu Inc, Kyoto) for all Ni-based alloys. The casting procedures were carried out similar to the previous study[9].

The properties investigated were the microstructural features and Vickers hardness and tensile properties. Their samples after casting were polished using the same methods as the previous studies[10-12]. Metallographic reagent for the structures of cast samples was 10% Nital etchant (10 mL HNO_3/ 90 mL ethanol)[12]. The hardness values were measured when 200 gram load was applied to the specimen (15×20×2.5 mm). The reported values mean the range obtained for test samples. Tensile properties were obtained using tensile stress-strain curves at 1.0 mm/min as a cross-head speed (Shimadzu DCS-500, Kyoto).

RESULTS

The cast microstructures were shown in Fig. 1 (sixteen dental Ni-based alloys). The structures were composed of dendrite structure and also interdendrite structure between the dendrites. Typically the interdendrite structure was corroded by the etchant. The structures were also analyzed by a grain size or cell size as cellular dendrite structures.

Fig. 2 (a) and (b) show the hardness number of ingot Ni-based alloys tested, and Fig. 3 (a) and (b) show its value of cast Ni- based alloys after casting. H and S, respectively, mean the hardness numbers in age-hardened and softened conditions. The magnitude of hardness in code 1 to 8 was near the level of 220 (Fig. 2(a)), and its magnitude in code 9 to 15 more than 220 (Fig. 2 (b)). The magnitude in cast samples was less than 150 and 150

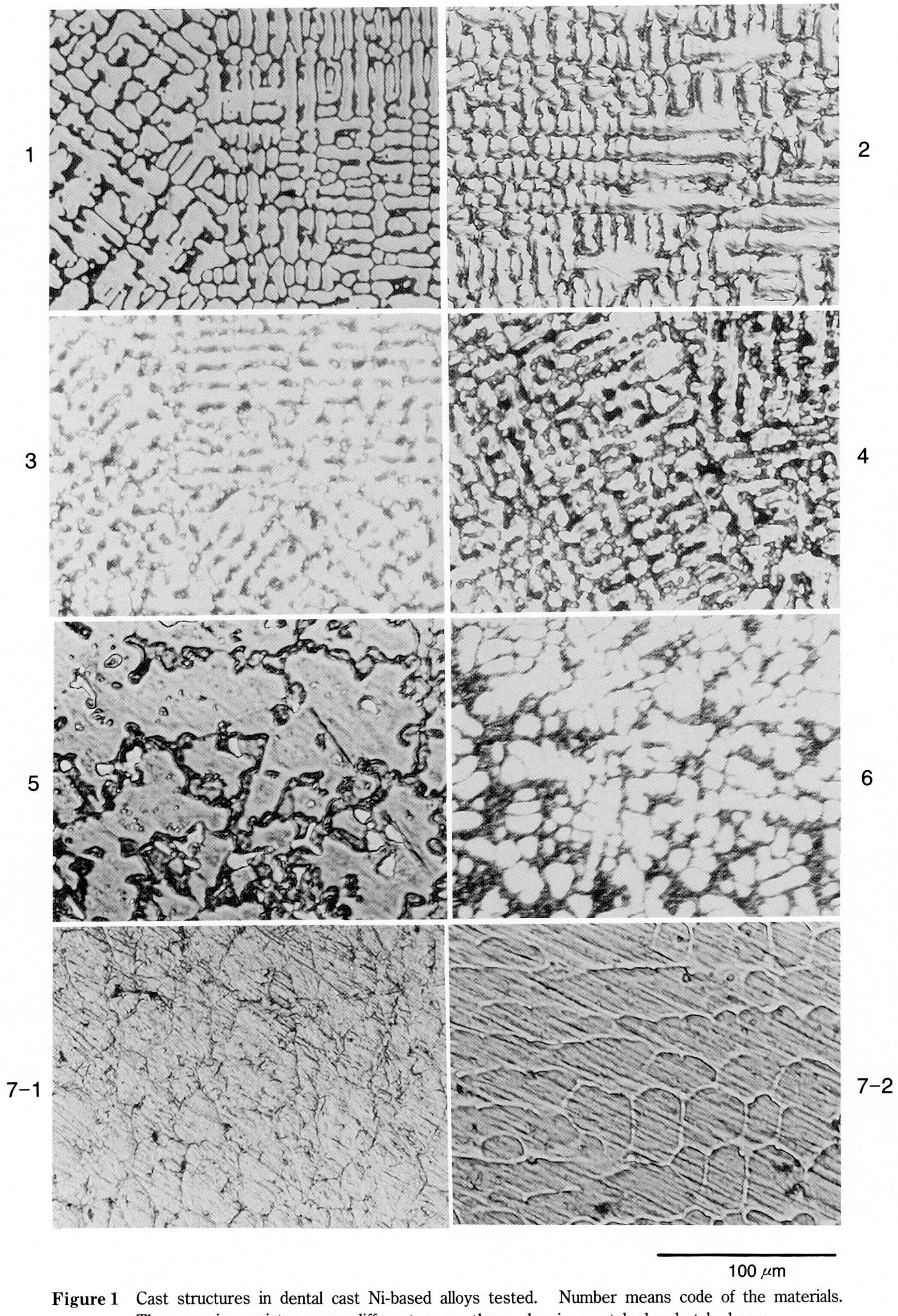

Figure 1 Cast structures in dental cast Ni-based alloys tested. Number means code of the materials. The corrosive resistance was different among them, showing unetched and etched area.

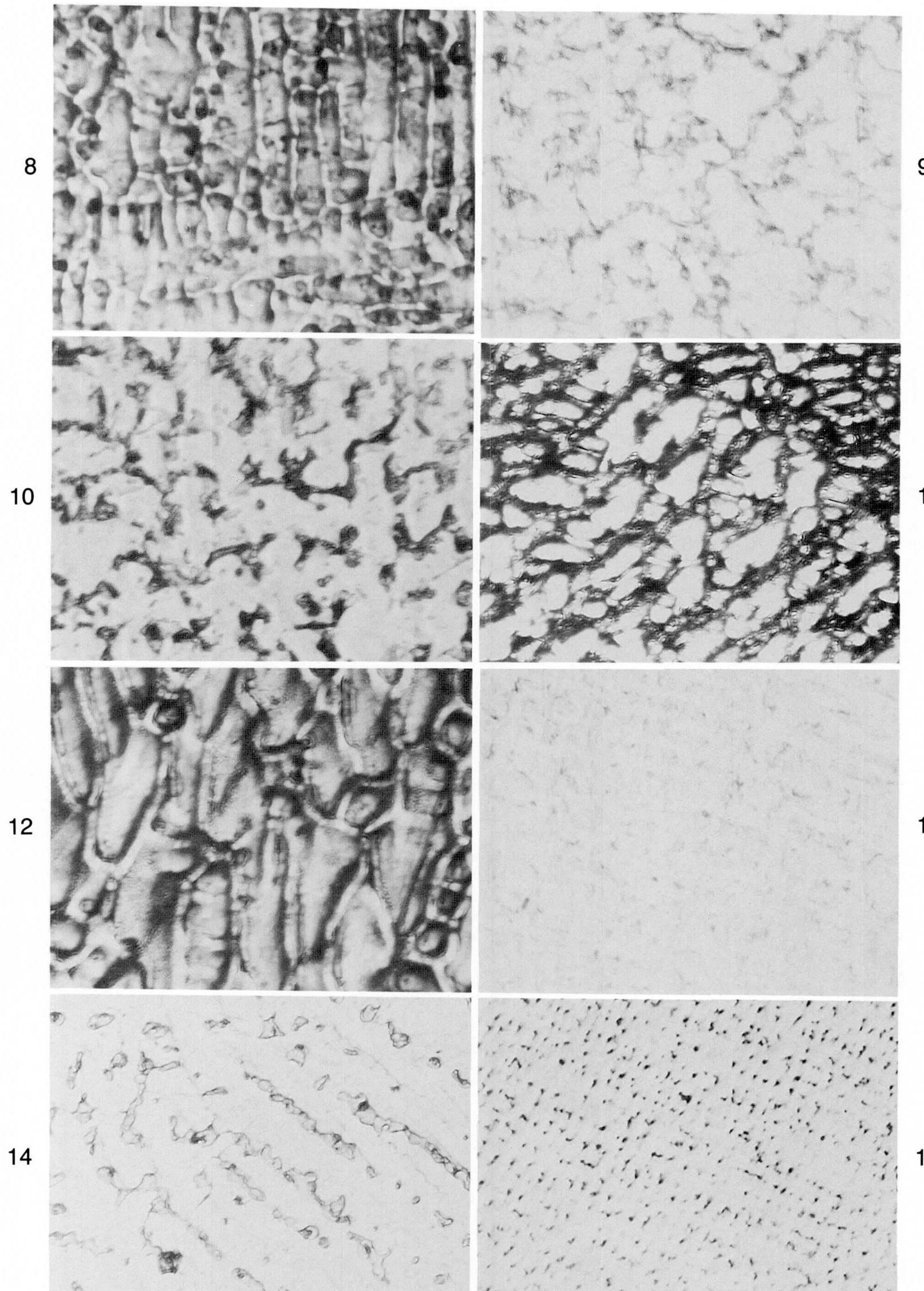

Figure 1 (Continued)

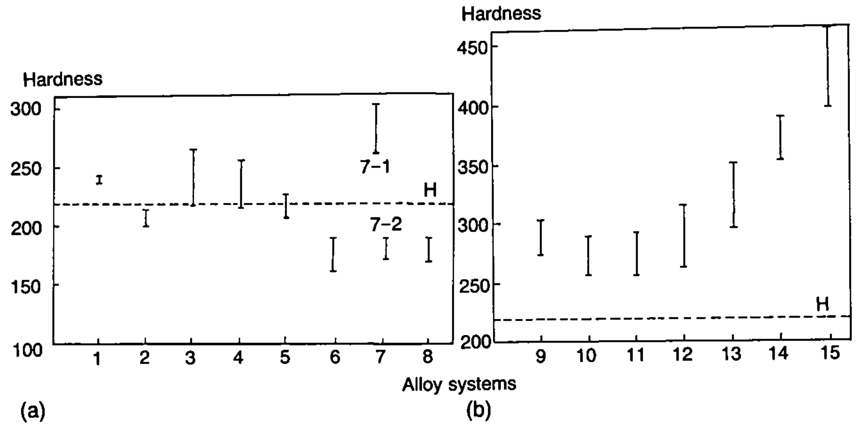

Figure 2 Hardness number in ingot materials. (a) Code 1 to 8, and (b) code 9 to 15. See text for key. The hardness of microstructures which were etched was examined, and the ingots were classified by ADA specification.

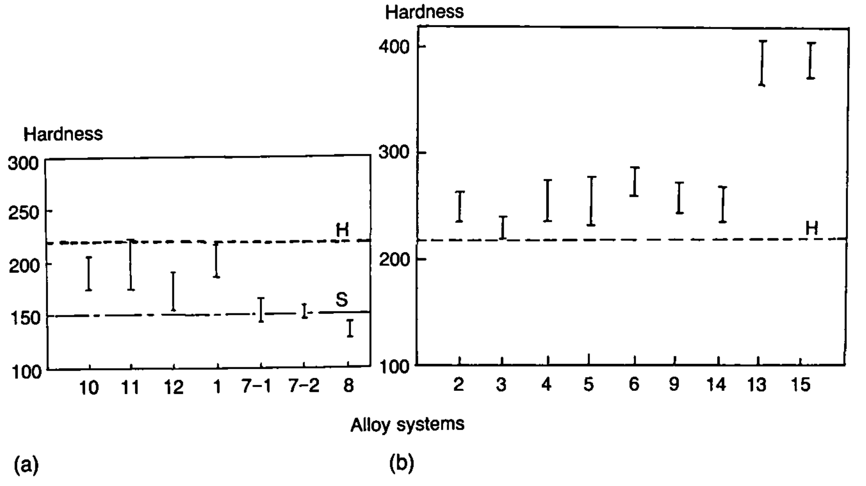

Figure 3 Hardness number in cast materials. (a) Soft alloy system (code 10, 11, 12, 1, 7–1, 7–2, 8), and (b) hard alloy system (code 2 to 6, 9, 14, 13, 15). The classification was indicated by gold alloy Type IV (ADA specification), and S and H mean solid solution treatment and age-hardened treatment, respectively.

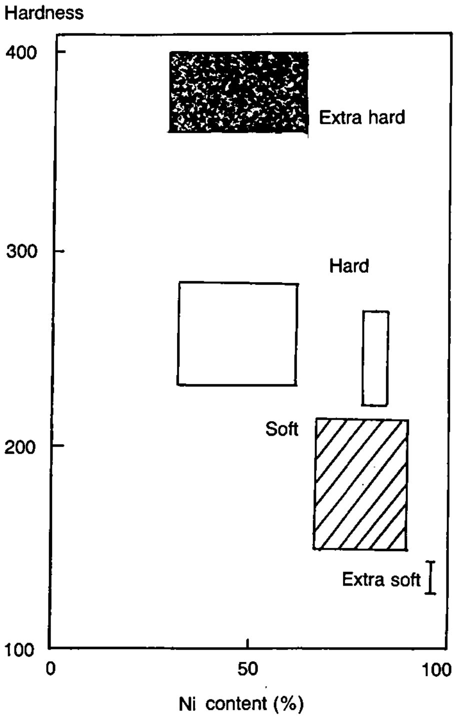

Figure 4 The relation of hardness with respect to Ni content in Ni-based alloys. The specification of casting gold alloys was referred.

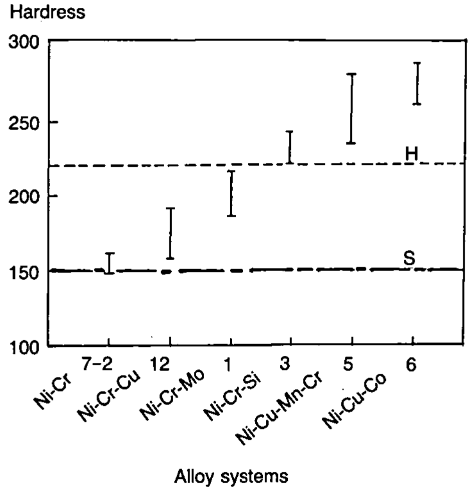

Figure 5 The value of hardness number in the alloy systems tested (code 7-2, 12, 1, 3, 5, 6). S and H (symbol) are the same as Figs. 2 and 3, and these symbols are used for Ni-based alloy systems tested in this study.

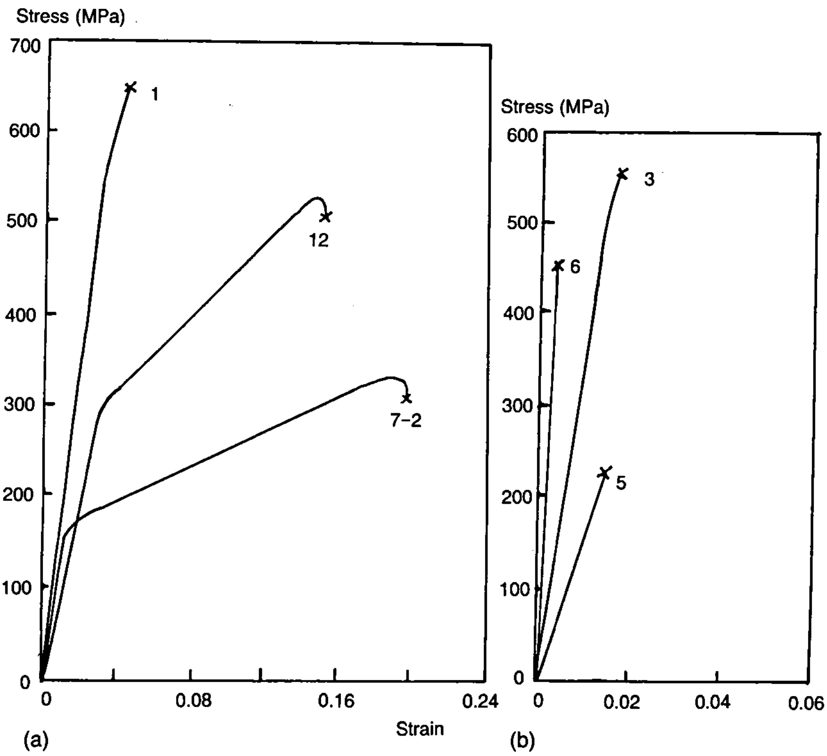

Figure 6 Examples; tensile stress-strain behaviours in code 1, 7-2 and 12 (a) and code 3, 5 and 6 (b).

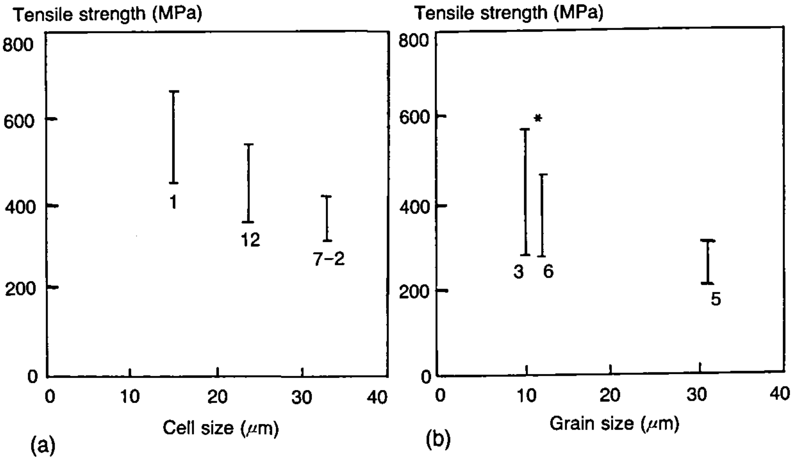

Figure 7 Relation of tensile strength and cell size (a) and grain size (b) in the same alloys as Fig. 6. Symbol * means dendrite arm length. See Figs. 8 for the comment of tensile fracture strength.

to 220 for seven samples of code 10, 11, 12, 1, 7–1, 7–2, 8 (Fig. 3 (a)), and the magnitude was more than 220 for nine samples of code 2 to 6, 9, 14, 13, 15 (Fig. 3 (b)).

Fig. 4 shows the relation between Ni content and hardness number in dental Ni-based alloys, refering to the specification of casting gold alloys, representing that extra soft (120 to 150), soft (150 to 220), hard (220 to 280) and extra hard type (360 to 400) were found newly for the Ni-based alloys.

Fig. 5 shows typical examples of hardness number in six cast Ni-based alloy systems tested, representing that the Ni-based alloys of less than 220 as the soft type (7–2, 12, 1 as code) and the other alloys were more than 220 as the hard type (3, 5, 6 as code).

Figs. 6 (a) and (b) show examples of tensile stress-strain behaviours in soft type (code 1, 7–2, 12) and hard type Ni-based alloy systems (code 3, 5, 6), representing that the soft one had higher strain and the hard one showed lower tensile strain.

In Figs. 7 (a) and (b), which show the relation between cell size and tensile strength for the soft type (code 1, 7–2, 12) and the one between grain size and tensile strength for the hard type (code 3, 5, 6), the increased size exhibited the decrease of tensile strength. Fig. 8 is the relation of tensile strength to the hardness number in Ni-based alloys tested, showing that soft type exhibited the higher tensile strength (300 to 700 MPa) and the hard type was in the range of 200 to 600 MPa.

DISCUSSION

Dental Ni-based alloy systems tested were newly classified by soft and hard systems, showing that hardness number was ranging from about 150 to 220 (extra soft and soft types) and more than 220 (hard and extra hard types), refering to the specification of casting gold alloys and the previous study[13,14]. The classification due to hardness was indicated in Fig. 4 (dental Ni- based alloys). Dental casting gold alloys were specified as the Type I alloy (extra soft; Vickers number of less than 90, softened), Type II (soft; ranging from 90 to 120), Type III (hard; range between 120 to 150) and Type IV (extra hard; 150 or above after a softening treatment, and more than 220 for age-hardened condition).

Phosphate-bonded investment (Summavest) was used to cast the Ni-based alloys tested, so phosphate compounds in the investment reacted with each metal additive of cast Ni-based alloys. The tensile specimens had the same situation in the occurrence of porosity within the

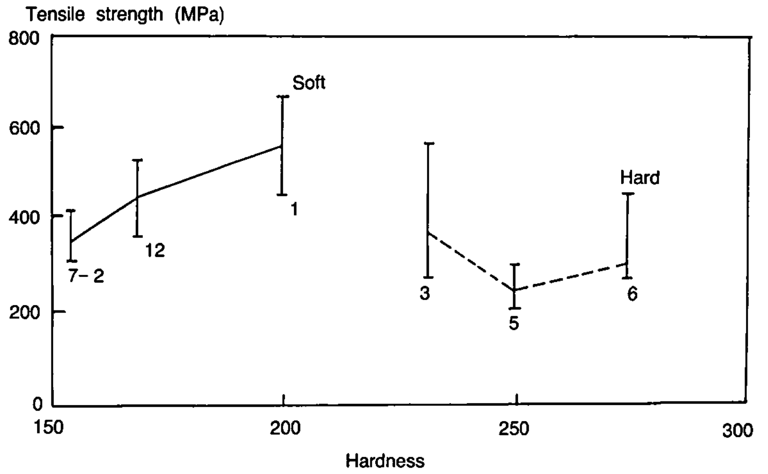

Figure 8 Tensile strength-hardness relation in Ni-based alloys. See Table 1 for key. From this relation, it was supposed that strength values were affected by grain size as the structure factor, as indicated in Fig. 7. Future work will be done to clarify this relation between grain size (structure) and strength (fracture) in Ni-based alloys.

specimens because gases escape from the investment mould.

As expected in Figs. 6 (a) and (b), higher tensile strain of the alloys tested was obtained for the soft type Ni-based alloys, associated with higher tensile strength (300 to 700 MPa), and lower tensile strain was found for the hard type Ni-based alloys with 200 to 600 MPa strength. The improvement of the alloy structure was done by metal additives in Ni-Cr-based alloys and Ni-Cu-based alloys. Ni content in Ni-Cr-based alloys controlled the magnitude of hardness number as indicated in higher Ni content-including alloys, and the metal additives in Ni-Cr-based alloys affected the magnitude of hardness number (Fig. 5). The parameter to represent alloy structure was either a grain size or cell size (Fig. 7). Based on the results in Figs. 6 and 7, the development of Ni-based alloys is done by selecting the additives in such Ni-based alloys as Ni-Cr-, Ni-Cu-based and the other alloy systems.

As reported previously[4-6,13], such additives as molybdenum, cobalt, silicon and manganese exhibited the increased values of hardness and tensile properties as compared with binary Ni-Cr-based alloys. Ni-Cu-based alloys had a low melting temperature of less than 1150°C (Table 2) and the additives were selected to control the mechanical property. The hardness and tensile property in the Ni-Cu-based hard type were controlled by manganese and cobalt as additives (Fig. 5). On the contrary, each metal additive was effective to change the mechanical property in Ni-Cr-based alloy, exhibiting the increased strength as a tensile behaviour.

SUMMARY

The hardness and tensile test exhibited structural characteristics of dental Ni-based matrix phase. Dental Ni-based alloys were composed by two groups of Ni-Cr-based and Ni-Cu-based alloys with dendrite structure. Their alloys were classified using the specification of gold alloys. With respect to hardness and tensile property, the Ni-based alloys were specified by two groups with higher strain and smaller hardness (soft type) and lower strain and larger hardness (hard type). Tensile strength value was found between 200 to 700 MPa for these types. These results suggest that the mechanical property in dental Ni-based alloys as Ni-Cr-based and Ni-Cu-based alloys are controlled by the additives in their alloys.

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