Change in Compressive Strength of Amalgams by Corrosion

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Introduction

It has been demonstrated by Phillips, *et al.* (1954)¹⁾ and Eames, *et al.* (1973)²⁾ that the compressive strength of amalgam might be slightly increasing in air at room temperature even at the end of a six-month period, while it was deleteriously affected by moisture contamination. Patel, *et al.* (1979)³⁾ also found that the ageing of specimen in air at 37°C for four months had no effects on the compressive strength of several commercial high-copper type amalgams.

On the other hand, it has been evidenced through experimental and clinical studies^{4~6)} that the high-copper type amalgams were superior in mechanical properties to the conventional type ones. Better corrosion resistance of a high-copper amalgam, Dispersalloy, was also claimed through the clinical evaluation by Duperon, *et al.* (1971)⁷⁾ and the test of the polarization resistance by Sarkar, *et al.* (1975)⁸⁾. The authors (1981)^{9, 10)} showed in a series of studies on *in vitro* corrosion of amalgam that the conventional lathe cut and spherical amalgams were severely attacked by saline solution to yield extreme corrosion products and microstructure disturbance. The high-copper amalgams generally did not exhibit so marked changes in appearance as the conventional ones. However, they released much larger amounts of Cu and Hg in saline solution at the later stage of a six-month period than the conventional ones. Espevik (1977)¹¹⁾ also reported previously that Dispersalloy exhibited larger Cu dissolution in artificial saliva than other conventional and high-copper amalgams.

The present study was scheduled to determine the effects of ageing in corrosive solution on the compressive strength of various types of amalgams in relation to their different corrosion behaviors.

Materials and Methods

Eleven amalgam alloys of different types and systems were selected as listed in Table 1. Alloys D, D*, E and I* are high-copper type amalgams. The mercury-alloy ratios and trituration conditions used followed the manufacturer's directions. Specimens 4 mm in diameter and 8 mm in length were prepared with a mechanical

Table 1 Amalgam alloys tested

	Alloy	Code	Manufacturer
Lathe cut Ag-Sn	Micro Alloy	M	L. D. Caulk, Milford, DE, U.S.A.
	Micro Alloy*	M*	L. D. Caulk, Milford, DE, U.S.A.
	Velvalloy	V	S. S. White, Philadelphia, PA, U.S.A.
	Velvalloy*	V*	S. S. White, Philadelphia, PA, U.S.A.
Spherical Ag-Sn	Spheraloy	S	Kerr Mfg., Romulus, MI, U.S.A.
	Spher-A-Caps*	S*	Kerr Mfg., Romulus, MI, U.S.A.
	Shofu Spherical*	Ss*	Shofu Dental Mfg., Kyoto, Japan
Lathe cut Ag-Sn admixed with spherical (Ag-Cu)	Dispersalloy	D	Johnson & Johnson, East Windsor, NJ, U.S.A.
	Dispersalloy*	D*	Johnson & Johnson, East Windsor, NJ, U.S.A.
	Ease	E	L. D. Caulk, Milford, DE, U.S.A.
Spherical (Ag-Sn-Cu)	Indiloy**	I *	Shofu Dental Mfg., Kyoto, Japan

*contains no Zn

**contains In

Table 2 Storage of amalgam specimens prior to compression test

Storage	Code
in air at 37°C for 1 week	1 <i>wA</i>
in distilled water at 37°C for 1 week	1 <i>wW</i>
in 0.5% sodium chloride solution at 37°C for 1 week	1 <i>wS</i>
in distilled water at 37°C for 3 months	3 <i>mW</i>
in 0.5% sodium chloride solution at 37°C for 3 months	3 <i>mS</i>
in distilled water at 37°C for 6 months	6 <i>mW</i>
in 0.5% sodium chloride solution at 37°C for 6 months	6 <i>mS</i>

dynamic condensor. Prior to compression test, each specimen was suspended using a small basket in 50 ml of distilled water or 0.5 per cent sodium chloride solution for various periods as shown in Table 2. The water or the saline solution was replaced with fresh one every month. Compression tests were conducted with a universal testing machine at a loading speed of 0.25 mm/min. Three specimens were prepared for each test. Another three specimens were tested after having been stored in air at 37°C for one week as the standards.

Results

Figure 1 shows the compressive strength of amalgams after each storage. Average percent changes in strength as compared with the standard strength obtained from one-week specimens in air are summarized in Table 3. Analysis of variance revealed that the changes in compressive strength differed significantly by the types of alloys and storage conditions as well as the interaction of these factors. Table 4 is the list of the alloys in which the significant difference in compressive strength appeared between each two storage conditions by t-test. In most of the amalgams tested, no

Fig. 1 Compressive strength of amalgams

Table 3 Percent changes in compressive strength as compared with the specimen stored in air for one week (%)

	1 <i>wA</i>	1 <i>wW</i>	1 <i>wS</i>	3 <i>mW</i>	3 <i>mS</i>	6 <i>mW</i>	6 <i>mS</i>
M	0.0	-4.0	-9.2	10.9	14.8	-0.3	-3.2
M*	0.0	-2.5	-7.3	14.5	16.2	6.3	6.0
V	0.0	-3.6	-10.2	8.9	9.7	3.8	-5.9
V*	0.0	-3.8	-8.2	11.1	13.6	3.7	3.7
S	0.0	1.6	-2.7	19.1	10.6	1.5	5.9
S*	0.0	-1.5	-3.2	7.6	9.7	-2.8	1.7
Ss*	0.0	-0.3	0.0	16.9	15.3	3.8	10.0
D	0.0	-2.5	-7.1	15.9	11.0	7.6	9.4
D*	0.0	-6.1	-9.9	20.4	20.0	-6.1	17.5
E	0.0	6.4	-1.5	24.9	21.0	21.1	22.6
I*	0.0	2.3	-7.2	26.9	18.9	4.6	-30.9

Table 4 Alloys which exhibited significant difference in compressive strength between each two storage conditions by analysis of variance and t-test

1 <i>wA</i>	—						
1 <i>wW</i>	D*	—					
1 <i>wS</i>	MM* V V*	M* V*	—				
3 <i>mW</i>	MM* V V*	MM* V V*	MM* V V*	—			
	S S* Ss*	S S* Ss*	S S* Ss*				
	DD* E I*	DD* E I*	DD* E I*				
3 <i>mS</i>	MM* V V*	MM* V V*	MM* V V*	S	—		
	S S* Ss*	S S* Ss*	S S* Ss*				
	DD* E I*	DD* I*	DD* E I*				
6 <i>mW</i>	M*	M* V V*	MM* V V*	MM* V*	MM* V V*	—	
	D* E	D	DE	S S* Ss*	S S* Ss*		
				D* I*	D*		
6 <i>mS</i>	M* V	M* V*	M* V V*	MM* V V*	MM* V V*	V	—
	Ss*	Ss*	S Ss*	S Ss*	S* Ss*	Ss*	
	DD* E I*	DD* I*	DD* E I*	I*	I*	D* I*	
	1 <i>wA</i>	1 <i>wW</i>	1 <i>wS</i>	3 <i>mW</i>	3 <i>mS</i>	6 <i>mS</i>	6 <i>mW</i>

differences were statistically found in strength between one-week specimens in water and in air. Saline solution, on the contrary, weakened the amalgams in one week, and significant decrease in strength was observed in all of the conventional lathe cut alloys and one high-copper alloy D*. Three-month specimens both in water and in saline solution exhibited much higher compressive strength than one-week specimens. The increment of the strength was generally larger in the high-copper amalgams than in the conventional ones. There were no differences in strength between the specimens stored in water or in saline solution for three months except for alloy S.

Continued immersion of the specimen in the water or the saline solution over a six-month period resulted in decreased compressive strength. Especially amalgam I* showed a drastic decrease in strength to the minimum value of all in the saline solution after six months, although it was the strongest under any other storage conditions. High-copper amalgams D and E showed no significant differences between the three-month specimens and the six-month ones.

Discussion

Compressive strength of amalgam specimen after one week storage in air varied with the type of amalgam. In general the high-copper type amalgams showed the highest strength, followed by the conventional type spherical ones and the conventional lathe cut ones. The compressive strength was not changed statistically by storing the specimen in distilled water for one week in most of the amalgams tested. On the contrary, saline solution caused a considerable decrease in compressive strength of amalgam during one week period. Statistically significant decreases appeared in all the conventional lathe cut amalgams M, M*, V and V*, and one high-copper amalgam D*. However, there could be observed no detectable microstructure changes nor corrosion products in these amalgams in such a short period. Phillips, *et al.*¹⁾ introduced the effect of the moisture contamination that decreased the compressive strength of Zn containing amalgam when the specimen was contaminated with saline solution for 30 seconds after trituration. Eames, *et al.*²⁾ also showed the rapid decrease in strength of both Zn containing and Zn free amalgams by contaminating them with saliva during condensation. The immersion of the specimen in the saline solution might have some effect of such contamination on the strength of amalgam. In any way the conventional lathe cut amalgams may be susceptible to the corrosive attack at the initial stages of setting so far as the compressive strength is concerned.

It has been demonstrated that the compressive strength of amalgam may be slightly increasing in air even at the end of a six-month period.^{1, 2)} In this experiment, however, all the amalgams exhibited a common tendency that the compressive strength of the three-month specimen was higher than that of the one-week specimen or the six-month one both in distilled water and in saline solution. The authors reported that the corrosion of amalgam in the saline solution was lowered with time up to

around the third month and then activated markedly.⁹⁾ Especially in the conventional amalgams, dramatic corrosion products and microstructure changes could be observed.¹⁰⁾ It might be referred to the prominent corrosion of amalgam that the highly significant decrease in strength was found in the conventional amalgams during the period from the fourth to sixth month. Although dissolution of the amalgam into the distilled water was very small even at the later stage of immersion⁹⁾, the water appeared to give a deleterious effect on the compressive strength as severely as the saline solution did.

It was shown by Youdelis (1979)^{12,13)} that the addition of In powder to amalgam alloy significantly increased one-hour and 24-hour compressive strength with In content up to 10 per cent. The original alloy particles of the high-copper amalgam I* are composed of Ag-Sn-Cu ternary system and include a small amount of In. I* was stronger than any other amalgams also in one-week or three-month storage, but it was markedly deteriorated to show the minimum strength of all by six-month immersion in the saline solution. Extremely large amounts of Cu and Hg were released from this amalgam specimen into the solution during a three-month period from the fourth to sixth month⁹⁾, resulting in marked microstructure changes and corrosion products¹⁰⁾. A sharp reduction of the strength of this amalgam after six-month immersion in the saline solution would be associated with such changes in composition and severely disturbed microstructure. It could not be assured whether these singular phenomena were due to the very fact that the original alloy is a ternary system or that the element In is present.

High-copper amalgams except I*, on the contrary, maintained considerable strength over a six-month period in the saline solution. In amalgam E, rather a small increase was observed in the strength. These amalgams appeared to be less influenced by the immersion in the saline solution than the conventional lathe cut amalgams as to the compressive strength. It could be supported by the fact that relatively sound microstructures were observed in these high-copper amalgams even after six-month immersion in the saline solution¹⁰⁾. Conventional spherical amalgams showed tendencies in strength something similar to the high-copper ones, even though not a small amount of corrosion products and microstructure changes were recognized.

Compressive strength of Zn containing alloy was not so different from that of Zn free alloy of the same brand, when they were stored in air for one week. However, one-week and six-month specimens of the former exhibited somewhat larger drops of the strength in the saline solution than in the distilled water as compared with those of the latter. It is considered that the Zn containing alloys might be slightly more susceptible to the attack of the saline solution than the Zn free alloys in respect to the compressive strength.

Summary

Conventional lathe cut amalgams showed a significant decrease in compressive

strength when stored in 0.5 per cent saline solution for one week. The compressive strength increased by three-month storage in distilled water or in saline solution for all of the amalgams tested. Then the significant decrease was found in the strength of all of the conventional lathe cut amalgams and some of the conventional spherical and high-copper type ones during the three-month period from the fourth to sixth month in water and saline solution. High-copper type amalgams seemed to be the most resistant to corrosive attack in respect to the compressive strength. Exceptionally a ternary system of high-copper amalgam containing In exhibited a marked reduction in strength by placing it in the saline solution for six months. Zn free alloys were slightly insensitive to the attack of the saline solution as compared with Zn containing alloys of the same brand.

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アマルガム圧縮強さの腐食による変化

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各種アマルガムの圧縮強さにおよぼす腐食の影響を調べた。含亜鉛ならびに無亜鉛の従来型削片状アマルガム、球状アマルガムおよび高銅型アマルガム11種を用い、37°C 水中あるいは0.5%食塩水中に1週間、3カ月、6カ月浸漬した後、圧縮強さを測定した。水中に1週間浸漬しても圧縮強さの低下はみられなかったが、食塩水中に浸漬すると、従来型削片状アマルガムにおいて、空気中に1週間保存した対照群に比して7~10%の低下が認められた。3カ月経過すると、水中、食塩水中いずれにおいても使用したアマルガムすべてに圧縮強さの増加がみられた。その後6カ月目までの3カ月間に強さは低下したが、その減少量はアマルガムのタイプによ

って異なっていた。従来型削片状アマルガムが比較的大きな低下を示した。削片状γ合金に球状Ag-Cu共晶合金を加えた高銅型アマルガムには、食塩水中においても有意な低下は認められなかった。圧縮強さに関する限り、これらの合金は最も腐食の影響が少ないといえる。Inを含むAg-Sn-Cu三元合金から成る高銅型アマルガムは3カ月まで他のいずれのアマルガムより高い圧縮強さを示したが、6カ月経過すると強さは著しく低下し、最も弱いものとなった。無亜鉛アマルガムは同じ商品名の含亜鉛アマルガムに比して、わずかに食塩水の影響による強さの低下が少ないという傾向が認められた。