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THE EFFECT OF POROSITY AND MERCURY CONTENT UPON THE STRENGTH OF SILVER AMALGAM

by

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INTRODUCTION

In the literature dealing with the strength of silver amalgam variations in this property have been ascribed, almost exclusively, to its residual mercury content. The influence of the alloy composition upon the crushing strength of amalgam has received little attention, and so far, no studies seem to have been reported on the significance of the porosity of the amalgam.

The present study was undertaken to investigate the relation between the crushing strength, mercury content, and porosity at constant composition of the alloy.

METHODS

All the tests were carried out with the same commercial alloy (True Dentalloy®, S. S. White Dental Mfg. Co., G.B.), batch No. 926503. Variation in mercury content and porosity was obtained by varying 1) the initial ratio of mercury to alloy at the time of

start of condensation, 2) the mixing time, 3) the time interval between start of trituration and condensation, 4) the condensation pressure, and 5) the duration of condensation.

The amalgam specimens were made by a standard method described in a previous article (*Jørgensen et al.*, 1964). Alloy and mercury were weighed with an accuracy of ± 0.5 mg (the amount of alloy was constant in all experiments). Mixing was done in a Wig-L-Bug amalgamator, normally 20 seconds with pestle plus 2 seconds without pestle. Condensation began 2 minutes after start of trituration, and a constant pressure of 40 kg was used for 3 minutes. The crushing strength was measured after 168 ± 2 hours by means of a Losenhausen testing machine at a loading rate of 10 kg per second. Before the crushing test the end surfaces of the specimens were ground plane-parallel and their length reduced to 9.0 ± 0.5 mm by grinding.

The mercury content of the specimens was determined as the difference by weight between the mercury used in the mix and the expressed mercury, the latter being regarded as pure mercury (cf. *Jørgensen et al.*, 1964).

Porosity determinations were made in the following way. Immediately after preparation, before removal from the cylindrical mold, the length of the specimen was measured with a maximum error of 0.01 mm. The weight of expressed mercury was divided by the specific gravity of the mercury, and by the surface area of the cylindrical specimen. By adding the resulting figure to the length of the specimen a measure was obtained for the length of a specimen consisting of a constant amount of alloy and mercury, but an unknown amount of porosity.

As already pointed out, the amount of alloy was held constant, and so was, as a rule, the amount of mercury (58.14 %). In one experimental group the mercury ratio was varied systematically (see Table I), and for the purpose of measuring the porosity in these specimens, their corrected length was calculated as if their initial mercury content had been 58.14 %.

In order to calculate the percentage porosity of the specimens three amalgam mixes were prepared, each consisting of 60 % mercury and the constant amount of alloy. The amalgam ball was gently removed from the mixing capsule, and after setting

Table I

The influence of initial mercury content upon final mercury content, porosity, and crushing strength

	44.99 %	47.01 %	50.00 %	55.00 %	58.14 %	60.00 %	65.00 %
Final mercury content %	45.0 ± 0.1	46.3 ± 0.5	45.8 ± 0.3	47.2 ± 0.5	47.0 ± 0.1	47.4 ± 0.6	48.7 ± 0.8
Porosity %	4.8 ± 0.6	2.8 ± 0.7	2.3 ± 0.3	1.2 ± 0.3	1.0 ± 0.3	1.1 ± 0.0	1.0 ± 0.3
Crushing strength kg/cm²	2375 ± 217	2957 ± 88	3395 ± 82	3970 ± 46	4176 ± 168	4177 ± 193	4062 ± 110

its specific gravity and volume were determined according to Archimedes' principle. On this basis was calculated the length of a cylindrical specimen with 58.14 % mercury, and of the same structure as the ball. The porosity of the individual balls was determined by the point counter method on polished sections. Out of the total 500 counts none fell on porosities. Thus, the calculated length is a measure for the length of a cylindrical specimen with the basis, π 2.5² mm², constant for the whole study, without porosities, and consisting of the constant amount of alloy mixed with 58.15 % mercury which also forms the basis for the whole study. The computed lengths for the three ball-shaped specimens were respectively 11.96, 11.98, and 12.01, averaging 11.98 mm.

Based on this figure the percentage porosity of the other specimens were computed. A specimen with a length of e.g. 12.47 mm thus has a porosity of

$$\frac{(12.47 - 11.98) \cdot 100}{11.98} = 4.09\ \%\,.$$

Ten specimens were prepared for all combinations of variables and the calculated mean values and standard deviations given in the tables.

Besides the mechanically condensed specimens, a number of

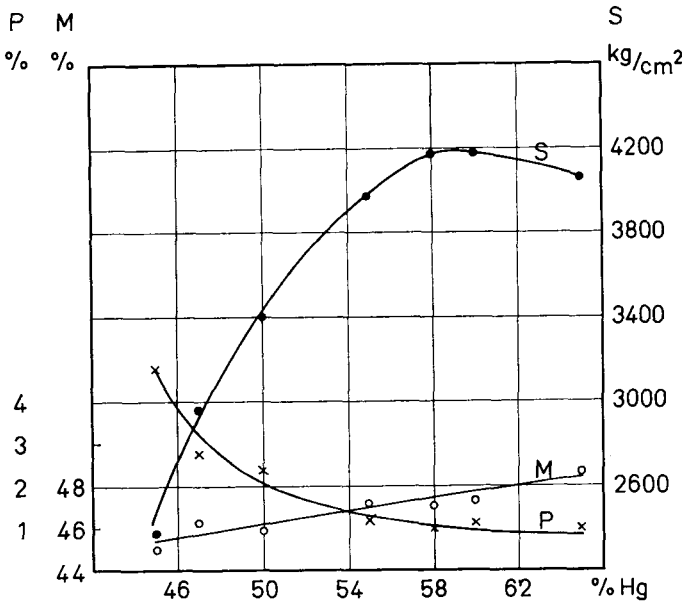

Fig. 1. Relation between porosity (P), mercury content (M), and strength (S) at varying initial mercury content. The initial mercury content is indicated in % on the axis of abscissas.

hand-condensed specimens were made, chiefly to investigate more closely the relation between the initial mercury content of the amalgam and its crushing strength. The method used in preparation of these specimens will be described in the second part of this paper.

Part 1

RESULTS

1. *Initial or primary mercury content.* The specimens were prepared with a constant amount of alloy (1.170 g) and varying amounts of mercury as shown in Table I. The results appear in Table I and Figure 1.

To examine more closely the effect of initial mercury content on strength and residual mercury content the experiments were repeated with certain variations as shown in Tables II and III. The crushing strength was measured already 72 ± 2 hours after

Table II

The influence of initial mercury content upon final mercury content and crushing strength (True Dentalloy)

		47 %	50 %	55 %	60 %	66⅔ %
Mixing time 60 sec. Condensation time 6 min.	Final mercury content %	46.6 ± 0.42	46.4 ± 0.47	47.7 ± 0.43	48.5 ± 0.33	50.8 ± 0.49
	Crushing strength kg/cm²	3255 ± 180	3572 ±151	3966 ± 109	4070 ± 80	3770 ± 23
Mixing time 30 sec. Condensation time 6 min.	Final mercury content %	45.8 ± 0.55	46.0 ± 0.44	47.0 ± 0.31	47.7 ± 0.51	48.7 ± 0.96
	Crushing strength kg/cm²	2909 ± 95	3175 ± 145	3597 ± 69	3917 ± 86	3724 ± 131
Mixing time 30 sec. Condensation time 3 min.	Final mercury content %	46.7 ± 0.23	46.6 ± 0.34	47.2 ± 0.21	48.2 ± 0.67	49.0 ± 0.47
	Crushing strength kg/cm²	2657 ± 158	2953 ± 64	3529 ± 128	3773 ± 95	3709 ± 39

Table III

The influence of initial mercury content upon final mercury content and crushing strength (STA 68)

		42 %	47 %	50 %	55 %	60 %	66⅔ %
Mixing time 60 sec. Condensation time 3 min.	Final mercury content %	39.9 ± 0.46	40.4 ± 0.24	41.1 ± 0.31	42.1 ± 0.37	43.6 ± 0.19	45.0 ±0.50
	Crushing strength kg/cm²	3268 ± 132	3756 ± 191	3965 ± 86	4115 ± 73	3933 ± 58	3774 ± 96
Mixing time 30 sec Condensation time 6 min.	Final mercury content %	37.2 ± 0.56	37.8 ± 0.40	38.4 ± 0.43	39.0 ± 0.37	40.0 ± 0.19	42.2 ± 0.27
	Crushing strength kg/cm²	3597 ± 126	3939 ± 114	4049 ± 68	4051 ± 68	3935 ± 57	3714 ± 78
Mixing time 30 sec Condensation time 3 min.	Final mercury content %	37.9 ± 0.14	39.2 ± 0.50	39.8 ± 0.27	40.3 ± 0.14	41.2 ± 0.31	43.7 ± 0.62
	Crushing strength kg/cm²	3422 ± 99	3765 ± 77	3913 ± 56	4033 ± 42	4004 ± 28	3677 ± 143

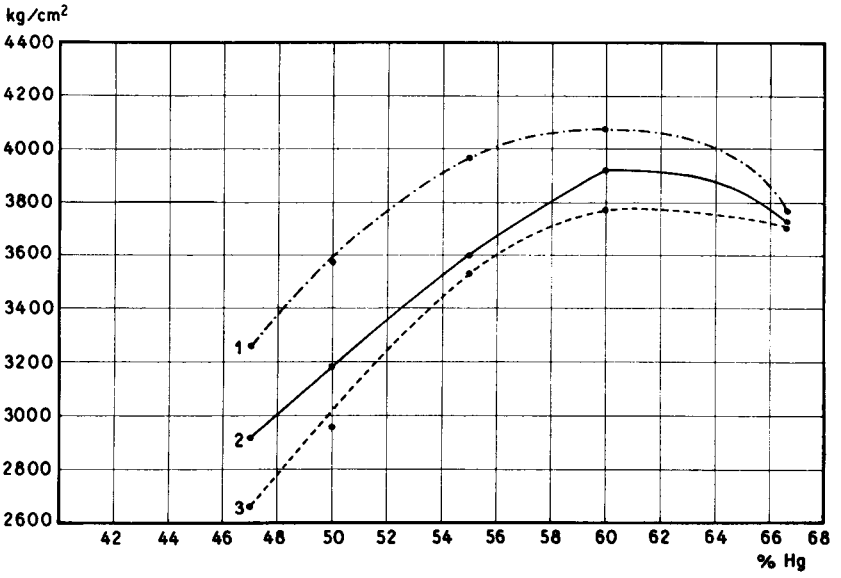

Fig. 2. Relation between initial mercury and crushing strength for True Dentalloy. Curve 1: 60 sec. mixing time, 3 min. condensation time. Curve 2: 30 sec. mixing time, 6 min. condensation time. Curve 3: 30 sec. mixing time, 3 min. condensation time.

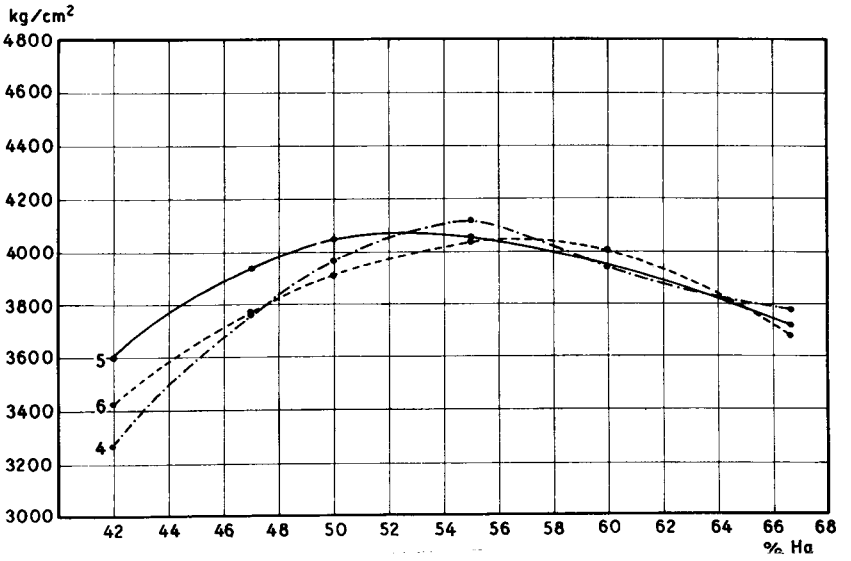

Fig. 3. Relation between initial mercury content and crushing strength for the preamalgamated brand STA 68. Curve 4: 60 sec. mixing time, 3 min. condensation time. Curve 5: 30 sec. mixing time, 6 min. condensation time. Curve 6: 30 sec. mixing time, 3 min. condensation time.

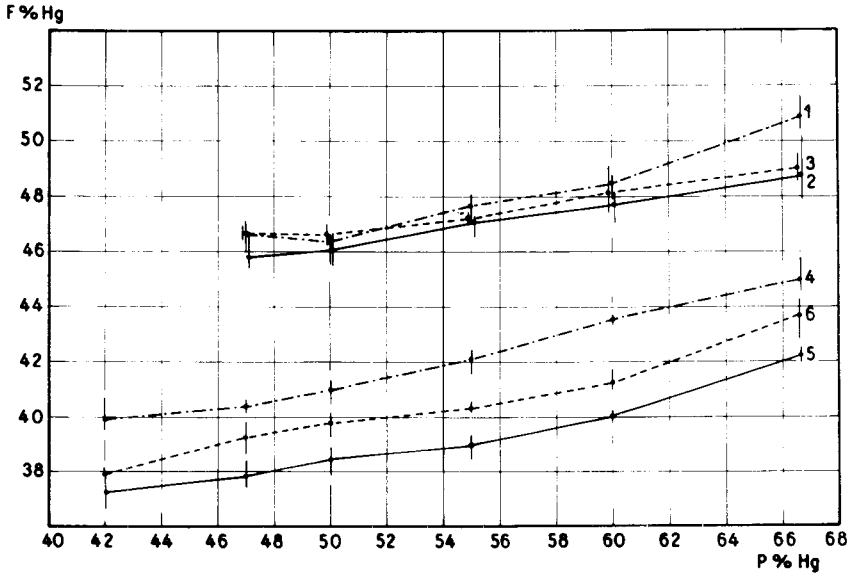

Fig. 4. Residual mercury content for the amalgams illustrated in Figs. 2 and 3. The short, vertical lines through the mean value points indicate highest and lowest experimental values.

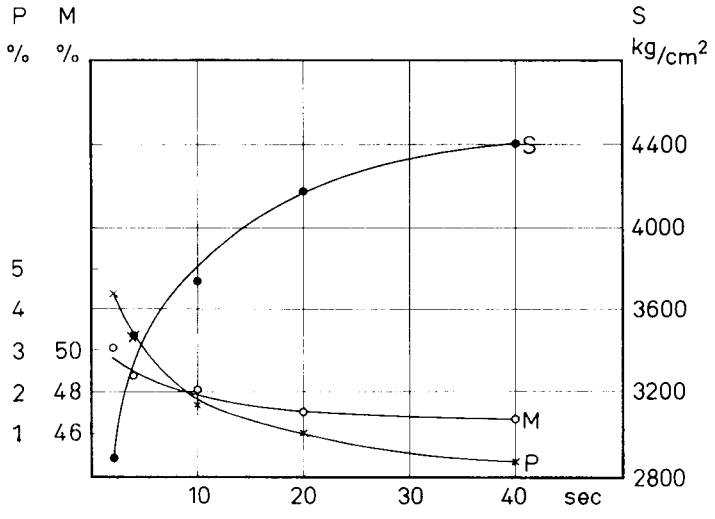

Fig. 5. Effect of trituration time upon the porosity (P), mercury content (M), and strength (S) of the amalgam.

Table IV

Effect of mixing time upon final mercury content, porosity, and crushing strength

	2 sec. +2	5 sec. +2	10 sec. +2	20 sec. +2	40 sec. +2
Final mercury content %	50.1 ± 0.5	48.8 ± 0.7	48.1 ± 0.4	47.0 ± 0.1	46.7 ± 0.5
Porosity %	4.4 ± 0.7	3.3 ± 0.5	1.7 ± 0.0	1.0 ± 0.3	0.3 ± 0.0
Crushing strength kg/cm²	2890 ± 199	3470 ± 117	3738 ± 120	4176 ± 168	4404 ± 123

condensation, and only five specimens were tested for each combination of variables. Besides True Dentalloy (batch No. 556220) these tests used the preamalgamated alloy STA 68 (Guldsmeds Aktiebolaget in Stockholm, G.A.B., batch No. 6254). The results are presented in Tables II and III and, by graph, in Figures 2, 3, and 4.

2. *The trituration time* was varied between 2 seconds and 40 seconds. The results are given in Table IV and Figure 5.

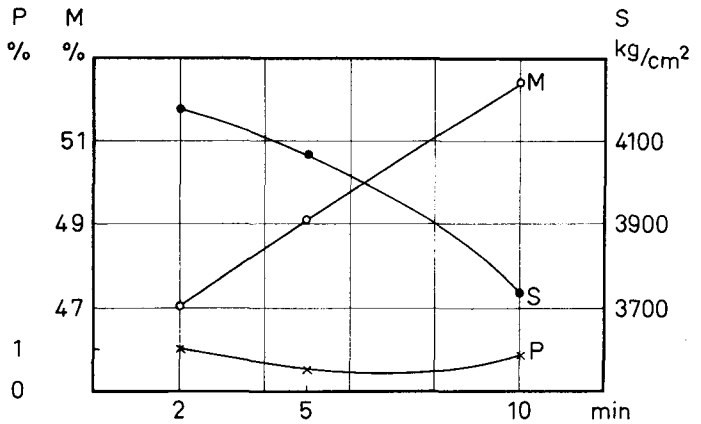

Fig. 6. Effect of the time between trituration and condensation upon porosity (P), mercury content (M), and strength (S) of the amalgam.

Table V

Effect of the time between trituration and condensation upon final mercury content, porosity, and crushing strength

	2 min.	5 min.	10 min.
Final mercury content %	47.0 ± 0.1	49.1 ± 0.5	52.4 ± 0.4
Porosity %	1.0 ± 0.3	0.5 ± 0.0	0.8 ± 0.3
Crushing strength kg/cm²	4176 ± 168	4065 ± 232	3735 ± 257

3. *The time interval* between start of trituration and condensation varied from 2 to 10 minutes. The results appear in Tables V and Figure 6.

4. *The condensation pressure* varied from 30 to 150 kg (about 1.5 kg/mm² and 7.5 kg/mm², respectively). The results are presented in Table VI and Figure 7.

5. *The condensation time* varied from 30 to 300 seconds. The results are presented in Table VII and Figure 8.

In addition to these tests a number of specimens were prepared with relatively high mercury content (55 % and 58.14 %) by shaking the freshly mixed amalgam into a cylindrical steel mold with upper and lower piston in place. The amalgam was

Table VI

Effect of condensation pressure upon final mercury content, porosity, and crushing strength

	30 kg	40 kg	60 kg	100 kg	150 kg
Final mercury content %	48.9 ± 0.5	47.0 ± 0.1	44.8 ± 0.5	40.4 ± 0.1	37.5 ± 0.5
Porosity %	0.9 ± 0.3	1.0 ± 0.3	1.0 ± 0.3	1.0 ± 0.3	0.8 ± 0.3
Crushing strength kg/cm²	4076 ± 115	4176 ± 168	4311 ± 144	4647 ± 98	4694 ± 45

Table VII

Effect of condensation time upon final mercury content, porosity, and crushing strength

	30 sec.	60 sec.	120 sec.	180 sec.	300 sec.
Final mercury content %	48.4 ± 0.4	48.1 ± 0.4	47.8 ± 0.4	47.0 ± 0.1	46.5 ± 0.4
Porosity %	1.6 ± 0.3	1.3 ± 0.0	1.0 ± 0.3	1.0 ± 0.3	0.9 ± 0.3
Crushing strength kg/cm²	3960 ± 155	3927 ± 202	4070 ± 97	4176 ± 168	4327 ± 96

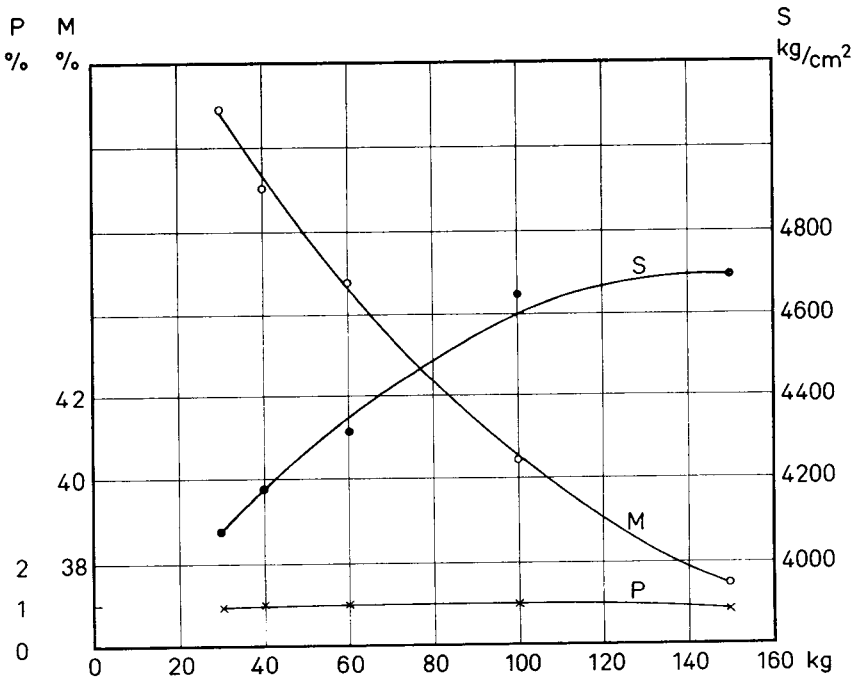

Fig. 7. Effect of condensation pressure upon porosity (P), mercury content (M), and strength (S).

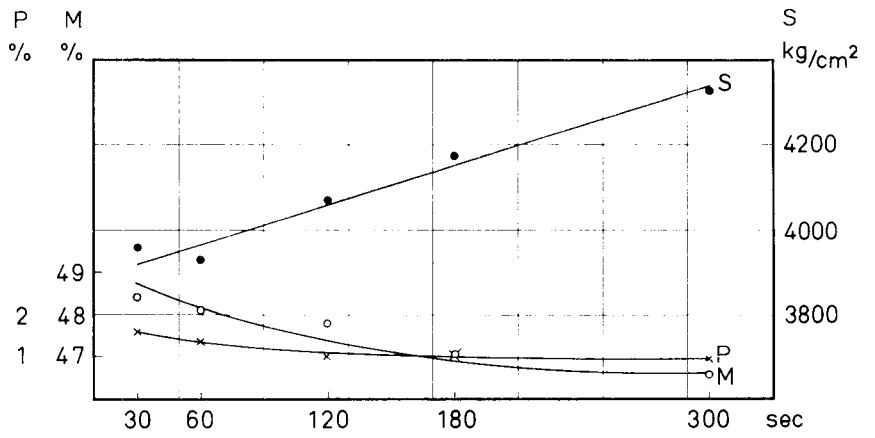

Fig. 8. Effect of condensation time on porosity (P), mercury content (M), and strength (S).

Table VIII

Final mercury content, porosity, and crushing strength of uncondensed amalgam specimens

Initial mercury content %	58.14	55.00
Final mercury content %	57.0 ± 0.6	54.8 ± 0.3
Porosity %	1.4 ± 0.3	3.4 ± 0.6
Crushing strength kg/cm²	3053 ± 290	3002 ± 193

shaken by gently tapping the steel mold against a table. In this way it is possible to shape the amalgam into regular cylinders without appreciable expression of mercury from the mix. There were 10 specimens in each group. The results are given in Table VIII, and together with the experimental data in Tables I, IV, V, VI, and VII they were used in constructing the diagrams in Figures 9 and 10.