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THE INFLUENCE OF CONDENSATION PRESSURE AND OTHER FACTORS ON DELAYED EXPANSION OF SILVER AMALGAM

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Although the phenomenon of delayed expansion of silver amalgam has been known since the beginning of this century there are still many unexplained points with regard to the factors which determine the amount of this type of expansion.

The purpose of the work described here was to investigate the effect of the following variables upon delayed expansion of silver amalgam, (1) condensation pressure, (2) particle size of the alloy, (3) expansion in cavities, (4) temperature, and (5) storage in solution of sodium chloride.

SURVEY OF LITERATURE

As early as 1908 *Black* described a slow expansion which occurred in amalgams containing zinc, and which might continue for several years and finally destroy the usefulness of the filling.

Liebig (1942) stated that "excessive expansion can be eliminated in amalgams contaminated with chlorides by reducing the amount of zinc added to the alloy". For alloys containing from 0.3 to 1.5 % zinc he found that the excessive expansion increased with increasing zinc content. In alloys with less than 0.3 % zinc he observed no excessive expansion at the end of seven days.

Ray (1942) found that the amount of expansion occurring in amalgam specimens over a period of one year seemed to depend

to a large extent upon the composition of the alloy, the technique of amalgamation and condensation, and the environment of the specimen. The particle size of the alloy had less influence.

Schoonover, Souder & Beall (1942) showed the delayed expansion to result from evolution of hydrogen by a chemical reaction between amalgam and water. Non-zinc alloys did not display expansion of this type.

Van Gunst & Hertog (1957) examined the relation between delayed expansion and the composition of alloys when the amalgam was contaminated with a constant quantity of a 2 % solution of sodium chloride. Using a number of alloy products with different composition they found that delayed expansion could be avoided only if less than 0.01 % zinc was present. They also demonstrated that the delayed expansion was governed by the zinc content if the latter was between 0 and 0.06 %. At higher percentages the amount of zinc was no longer the controlling factor, whereas a relation seemed to exist between delayed expansion and the quantity of copper in the alloy, in such a way that a higher copper content corresponded to a lower delayed expansion.

Kanatake and Takahashi (1960) studied the effect of a number of factors on delayed expansion. They found, *inter alia*, that there was no definite relation between the amount of zinc in the amalgan and the delayed expansion at zinc contents above 0.5 %, provided the zinc was present in the ingot from which the alloy was produced. Addition of increasing amounts of metallic zinc powder to a zincfree alloy showed, however, a clear relationship between zinc content and delayed expansion, i.e. the expansion increased with the quantity of zinc added. The authors found no relation between copper content and delayed expansion. Tests on alloys with varying particle size showed an increase in delayed expansion with the fineness of the alloy powder. Further, the delayed expansion was demonstrated to be higher in amalgam specimens kept at 37° C than in specimens kept at room temperature.

MATERIAL AND METHODS

The alloy used in the present experiments was made especially for this purpose by courtesy of Dentalaktiebolaget, Stockholm. Its composition was:

Silver	69.5 %
Tin	26.0 %
Copper	2.5 %
Zinc	2.0 %.

Screening of the alloy showed the grain size distribution to be as follows:

2.9 % was retained on a sieve with 150 μ meshes.

8.6 % could pass through a 150 μ mesh sieve, but was retained on a 90 μ mesh sieve.

30.1 % could pass through a 90 μ mesh sieve, but was retained on a 40 μ mesh sieve.

58.2 % could pass through a 40 μ mesh sieve.

The alloy-mercury ratio was 5/8 by weight. Approximately 1 g of alloy was mixed with 1.6 g of mercury in an electric amalgamator for 15 seconds. Immediately after mixing the amalgam was kneaded one minute in a rubber finger stall with 5—6 ml 1 % sodium chloride solution, after which it was transferred to a steel cylinder with a 5 mm diameter cavity, and a piston fitting within the cylinder was carried down on the amalgam.

The amalgam was condensed for 3 minutes under a predetermined, constant pressure transmitted to the piston by an Alpha durometer. The mold was then removed from the durometer, and one hour after condensation the test specimen was taken out of the mold.

A dial gauge (Carl Mahr, Germany) with reading accuracy of 0.001 mm was attached to a rigid frame in such a position that it registered 5.043 when a 10 mm gauge block was placed under the tip of the up- and down-movable rod. This position was maintained throughout the experimental period and used for measurements of test specimens, about 10 mm long. Later in the series, when 3 mm length specimens were made, another dial gauge was set accordingly.

The first reading was taken 24 hours after preparation of the specimens. They were then measured at regular intervals, at first every 24 hours, later once a week, until the final measurement was taken 60 days after preparation. Some of the specimens, however, were kept for an additional measurement 18 months after preparation.

RESULTS

1. Influence of condensation pressure upon delayed expansion

The effect of this factor was examined on 10 amalgam specimens condensed with each of the following pressures: 0.5 kg, 0.78 kg, 1.25 kg, 2 kg, 3 kg, and 5 kg per mm². The results of these tests are given in Table I and illustrated by the curve in Fig. 1.

Table I

Delayed expansion in amalgam specimens condensed with different pressures. Each value given for expansion is the average of ten tests.

Condensation pressure (kg/mm²)	Expansion in % after 60 days	Standard deviation
0.50	2.11	0.19
0.78	2.10	0.35
1.25	1.85	0.14
2.00	1.52	0.18
3.00	1.31	0.29
5.00	1.02	0.20

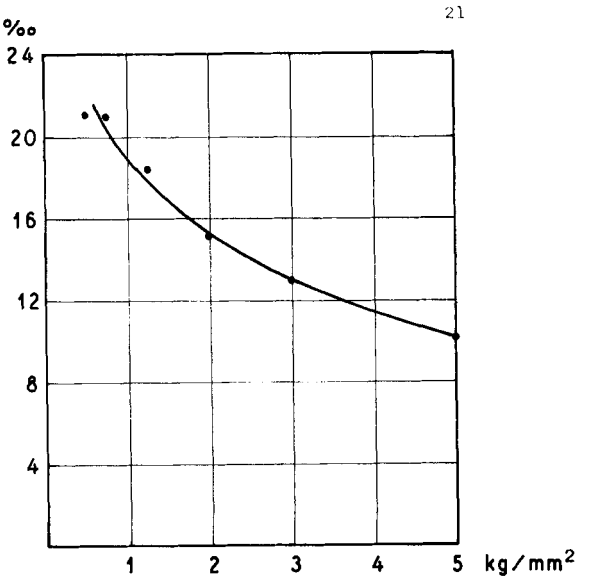

Fig. 1. Delayed expansion as influenced by the condensation pressure.

It is seen that the delayed expansion decreases as the condensation pressure is increased, but that even a pressure as high as 5 kg/mm² gives a delayed expansion of approx. 1 %.

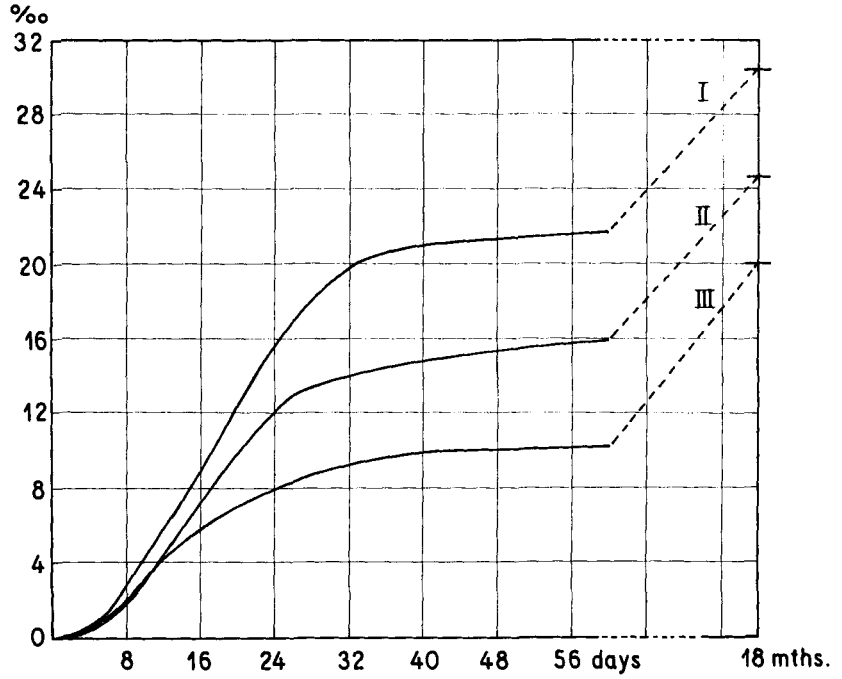

Fig. 2. Three typical expansion curves for amalgam specimens condensed with ½ kg/mm² (I), 2 kg/mm² (II), and 5 kg/mm² (III). An additional measurement 18 months after preparation showed that an appreciable expansion had taken place since the end of the first 60 days.

Fig. 2 shows three characteristic expansion curves for test specimens condensed with ½kg (I), 2 kg (II), and 5 kg (III) per mm², respectively. The delayed expansion is twice as large for the lowest condensation force as for condensation with 5 kg/mm². During the last part of the experimental period the expansion proceeded so slowly that it might lead to the conclusion that it was coming to an end. Measurement of the test specimens 18 months after preparation revealed, however, that a rather considerable expansion had occurred after the end of the 60-day period.

2. Influence of particle size on delayed expansion

For this series 10 specimens were prepared with such a fraction of the alloy as could pass through a 40 μ mesh sieve. After 60 days they exhibited an average delayed expansion of 0.84 $\pm$ 0.13 %, i.e. half the value obtained with the original alloy when the same condensation pressure was used. These findings disagree with those reported by *Kanatake & Takahashi,* but the two test series are hardly comparable since these workers studied the effect of coarse-grained versus fine-grained alloy types, while the present investigation concerns an unfractioned alloy as compared with a fine-grained fraction.

3. Delayed expansion in unconfined amalgam specimens and in specimens expanding in cavities

The previous experiments were all carried out with free specimens. It would be of interest to examine whether a delayed expansion of the same order would occur in amalgam expanding in a rigid mold. For this purpose 20 test specimens were condensed under a constant pressure (2 kg/mm²) in steel cylinders with cavities which were 5 mm in diameter and had smooth walls. The specimens were left in the molds throughout the testing period. The expansion found for these experiments showed a considerable increase over that obtained with a group of free specimens prepared under the same pressure. The findings appear in Table II, which also shows that the percentage expansion was

Table II

Expansion of free amalgam specimens and of specimens in cavities. The individual expansion values represent the averages of ten tests.

	Length of specimen	Expansion in % after 60 days	Standard deviation
Free specimens	approx. 10 mm	1.68	0.13
„ „	„ 3 „	2.33	0.59
Specimens in cavities	„ 10 „	2.14	0.35
„	„ 3 „	4.58	1.00

higher for specimens which were 3 mm long than for 10 mm specimens. The cause of this difference is unknown.

4. Influence of temperature and storage medium upon delayed expansion

All the tests in groups 1—3 were conducted at room temperature (22 ± 2° C). In order to make the experimental conditions more comparable to those of practice, 20 free specimens, about 10 mm long and condensed with a pressure of 2 kg/mm², were stored at 37° C, ten in air, and ten in a 1 % sodium chloride solution. The expansion results after 60 days are presented in Table III. There is no clear difference between the expansion of

Table III

Expansion of amalgam specimens stored at 37° C (each value representing the average of ten tests).

	Length of specimen	Stored in	Expansion in % after 60 days	Standard deviation
Free specimens	approx. 10 mm	air	1.86	0.36
„ „	„ 10 „	1 % NaCl	2.66	0.14
Specimens in cavities	„ 3 „	air	4.63	0.28
„	„ 3 „	1 % NaCl	11.43*)	2.96

*) average of six tests

the specimens kept in air at 37° C and that of corresponding specimens (Table II) kept at room temperature, although there seems to be a tendency towards a higher expansion at 37°. Storage in NaCl solution at 37°, on the other hand, gave a much higher expansion than storage in air at the same temperature.

Finally, 20 test specimens, approx. 3 mm in length, were prepared in cavities. The specimens were placed in an incubator at 37° C, ten in air, ten in a 1 % NaCl solution, to which was added 2.5 g Na_2CrO_4 per liter in order to prevent corrosion of the steel molds. For this group too the delayed expansion as given in Table III for storage in air at 37° was not very different from previous findings (Table II) for storage at room temperature. The specimens kept in NaCl solution at 37°, on the other hand, exhibited also in this case a much higher delayed expansion than those kept in air at the same temperature.

In the group of specimens in cavities in 1 % NaCl solution with Na_2CrO_4 at 37° C, four displayed reddish brown deposits of corrosion products on the surfaces at the end of the experimental period. These specimens were discarded. The remaining six had clean surfaces. All ten specimens in the group were characterized by a very rough surface with a tendency to bulge in the middle.

No explanation can be given of the increase in delayed expansion of the amalgam specimens kept in NaCl solution.

CONCLUSIONS

Delayed expansion in silver amalgam depends upon the force with which the amalgam is condensed, in such a way that higher pressure corresponds to lower expansion. The highest pressures within the dental range give, however, a delayed expansion of 1 %. It is therefore not possible, even by heavy condensation, to reduce the delayed expansion in amalgam to values which are negligible in practice.

Further, it has been demonstrated that the linear delayed expansion parallel to the walls of the mold as it occurs in amalgam expanding in a cylindrical cavity is much higher than for unconfined amalgam specimens. Therefore, tests with free specimens are only of relative interest from a clinical point of view. In applying laboratory results for free specimens to clinical conditions a larger expansion of clinical fillings must be expected.

The findings also show that there is only a slight difference in delayed expansion between amalgam kept in air at 37° C and at room temperature, while storage in sodium chloride solution at 37° gives a considerably higher expansion than storage in air at the same temperature.

SUMMARY

The purpose of the present investigation was to study the effect of the following factors upon the delayed expansion of silver amalgam, (1) condensation pressure, (2) grain size of the alloy, (3) expansion in cavities, (4) temperature, and (5) storage in sodium chloride solution.

The results are presented in Fig. 1 and 2, and in Tables I, II, and III. They show that the delayed expansion decreases as the

condensation pressure is increased, but not so much that it can be eliminated in practice even by using the highest possible packing pressure.

The delayed expansion was found to be smaller in a fine-grained amalgam than in a relatively coarse-grained one.

It was also shown that the linear delayed expansion is higher for amalgam expanding in a cylindrical cavity than for unconfined specimens. Therefore the results of laboratory experiments made on free specimens cannot be directly applied to amalgam in cavities.

Further the findings show that there is only a small difference between the delayed expansion of amalgam kept in air at 37° C and at room temperature (22 ± 2° C), while storage in a 1 % solution of sodium chloride at 37° C gives a considerably higher expansion than storage in air at the same temperature.

RÉSUMÉ

INFLUENCE DE LA PRESSION DE CONDENSATION ET D'AUTRES FACTEURS SUR L'EXPANSION TARDIVE DE L'AMALGAME D'ARGENT

Le but du présent travail est d'étudier l'effet des facteurs suivants sur l'expansion tardive de l'amalgame d'argent: 1) pression de condensation, 2) finesse du grain de l'alliage, 3) expansion dans les cavités, 4) température, et 5) conservation dans une solution de chlorure de sodium.

Les résultats sont présentés dans les figures 1 et 2, et dans les tableaux I, II et III. Ils montrent que l'expansion tardive diminue lorsque la pression de condensation augmente, mais insuffisamment pour pouvoir être éliminée en pratique, même en exerçant au bourrage la plus grande pression possible.

Il est apparu que l'expansion tardive était moins importante dans un amalgame à grain fin que dans un amalgame à relativement gros grain.

Il a été aussi mis en évidence que l'expansion tardive linéaire était plus élevée pour l'amalgame se dilatant dans une cavité cylindrique que pour des échantillons sans entrave. Les résultats d'expériences de laboratoire faites sur des échantillons libres ne peuvent donc pas être directement appliqués à l'amalgame dans les cavités.

Les résultats montrent en outre qu'il n'existe qu'une faible différence entre l'expansion tardive de l'amalgam gardé à l'air à une température de 37° C et à la température ambiante d'une pièce (22 ± 2° C), tandis que l'amalgame conservé dans une solution de 1 % de chlorure de sodium à 37° C présentait une expansion considérablement plus élevée que lors de la conservation à l'air à la même température.

ZUSAMMENFASSUNG

DER EINFLUSS DES STOPFDRUCKES UND ANDERER FAKTOREN AUF DIE NACHTRÄGLICHE AUSDEHNUNG IN SILBERAMALGAM

Es ist der Zweck dieser Arbeit zu untersuchen, ob die nachträgliche Ausdehnung in Silberamalgam von dem Druck abhängig ist, mit dem das Amalgam gestopft worden ist; ob die nachträgliche Ausdehnung in einem Amalgam, das aus sehr feinkörnigem Alloy hergestellt ist, ebenso gross ist wie in einem Amalgam, das aus relativ grobkörnigem Alloy hergestellt ist; ob die nachträgliche Ausdehnung linear in frei stehenden Versuchskörpern ebenso gross ist wie in Versuchskörpern, die sich in einer Form mit geschlossenem Boden ausdehnen; ob die Temperatur, bei der das Amalgam aufbewahrt wird, auf die nachträgliche Ausdehnung einen Einfluss hat; und schliesslich, ob die nachträgliche Ausdehnung die gleiche ist, wenn das Amalgam in einem Elektrolyt oder in Luft aufbewahrt wird.

Die Ergebnisse sind aus Abb. 1 und 2 und aus Tabellen I, II und III ersichtlich. Es geht hieraus hervor, dass die nachträgliche Ausdehnung mit steigendem Stopfdruck abnimmt, jedoch so, dass sie sich — selbst bei einem Stopfdruck, der an der Grenze des klinisch Erreichbaren liegt — nicht eliminieren lässt.

Es zeigte sich, dass die nachträgliche Ausdehnung im feinkörnigen Amalgam geringer war als im relativ grobkörnigen.

Aus den Versuchen geht hervor, dass die lineare nachträgliche Ausdehnung in Amalgam, das sich in einer Form mit geschlossenem Boden ausdeht, grösser ist als in frei stehenden Versuchskörpern, weshalb sich die Ergebnisse von Laboratoriumsversuchen mit frei stehenden Versuchskörpern nicht ohne weiteres auf Amalgam in Kavitäten übertragen lassen.

Ausserdem zeigt es sich, dass zwischen der nachträglichen Ausdehnung in Amalgam, das bei 37° trocken aufbewahrt wird, und der nachträglichen Ausdehnung in Amalgam, das bei Zimmertemperatur trocken aufbewahrt wird, nur ein geringer Unterschied besteht, wogegen Amalgam, das in einer 1 %-igen NaCl-Lösung bei 37° aufbewahrt wird, eine bedeutend grössere nachträgliche Ausdehnung aufweist als Amalgam, das in Luft bei der gleichen Temperatur aufbewahrt wird. Dieser Unterschied, dessen Ursache nicht klargelegt worden ist, kann dazu beitragen, einen Vergleich zwischen früheren Laboratoriumsversuchen und klinischen Verhältnissen zu erschweren.

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