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STRUCTURE STUDY OF AMALGAM

III. THE MARGINAL STRUCTURE OF CLASS II AMALGAM FILLINGS

by

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INTRODUCTION

The purpose of the present work is to analyze how various factors affect the structure of the vertical margins of Class II amalgam fillings. The structure was investigated by measuring the amount of gamma-phase and porosity. Since there is a regular relationship between the amounts of the three phases in amalgam (gamma, gamma 1, and gamma 2) from a given brand of alloy, determination of the amount of one phase will also be an expression of the amounts of the two others.

The amount of gamma-phase is an indirect measure for the mercury content of the amalgam, and hence a measure for those physical and chemical properties which are dependent upon the mercury content. The degree of porosity has considerable influence on the mechanical and electrochemical properties of amalgam. From a structural point of view the amalgam is the better, the more gamma-phase it contains, and the less porous it is (*Jørgensen et al.*, 1966).

METHODS

All the amalgam specimens were made by hand-condensation in a steel mold (Figure 1) shaped to represent a Class II cavity. To prevent damage to the margins of the specimens during removal from the mold the latter consisted of three separable parts,

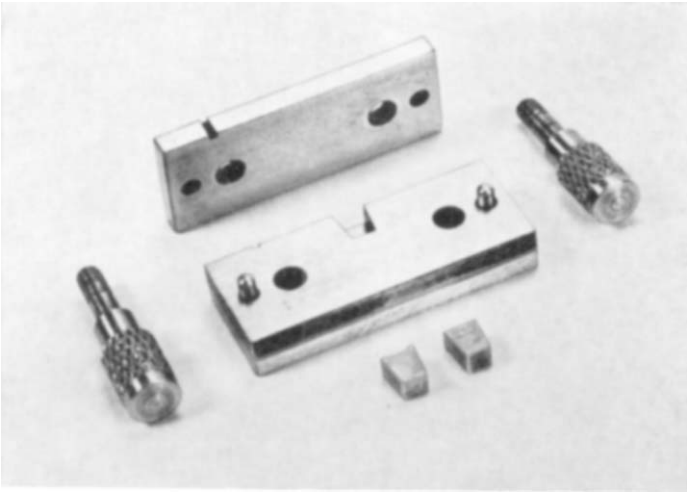

Fig. 1. Steel mold used in preparation of the amalgam specimens. The mold is partly separated. The two large holes in the steel plates were used in fixing the mold to the condensation balance.

the middle one with convergent walls. The mold was 3.0 × 3.0 mm in cross-section at the base and 3.0 × 3.8 mm at the opening, while its depth was 4.7 mm. The design of the mold enabled preparation of specimens with sharp vertical margins without

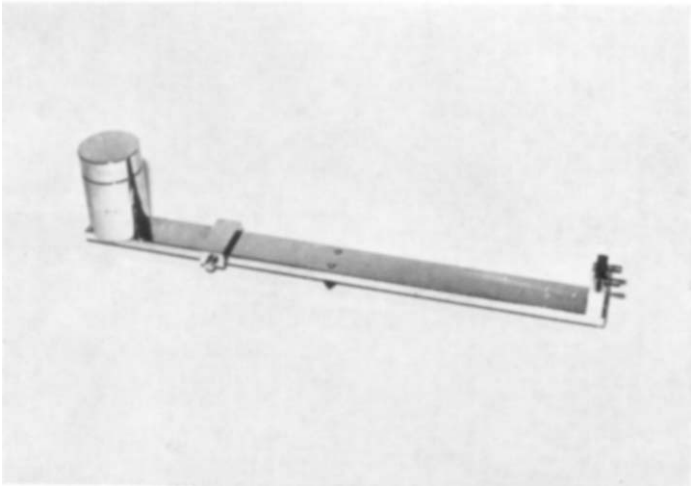

Fig. 2. Condensation balance with steel mold attached. The length of the balance is 50 cm.

rounding, an essential detail in the quantitative determination of marginal porosity.

Condensation was carried out on a specially designed balance (Figure 2) to ensure uniform condensing pressure. The individual thrusts on the amalgam surface lasted 1/2 to 3/4 seconds, and the intervals between them were of the same duration. True Dentalloy (The S. S. White Dental Mfg. Co. G.B.) was used throughout the investigation. In the normal tests the specimens were made up of 0.56 g of alloy and 0.77 g of mercury (the proportion was varied in special tests to be reported later). Trituration was accomplished in a Wig-L-Bug, where the material was mixed in bakelite capsule with pestle for 20 seconds + 2 seconds without pestle. Immediately after preparation of the mix the mercury content was reduced to 52 ± 0.5 % by expression of excess from

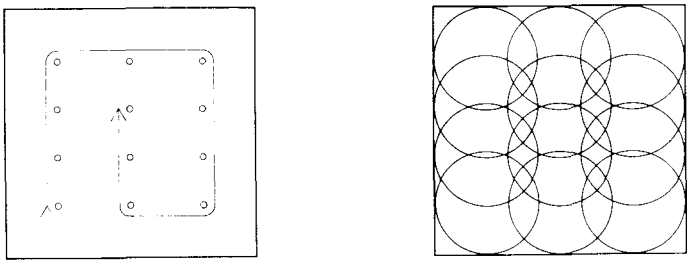

Fig. 3. Diagram illustrating the condensation of the individual increments of the amalgam. The circles indicate the area of the increment which was covered by a circular condenser point, 1.2 mm in diameter.

the whole mass. The amalgam was then divided into 8 pieces of about the same size, and each was condensed with 12 thrusts following the procedure diagrammed in Figure 3 regardless of the shape and size of the pluggers. Condensation began 2 minutes from start of the mix and occupied 4—5 minutes. Mercury excess was carefully removed after condensation of each increment, all of which were used in filling the mold. As soon as packing was finished the specimens were taken out of the mold in such a way that their margins remained intact.

Not earlier than 24 hours after preparation the specimens were embedded in a cold-curing plastic material (Palatal) where the temperature during polymerization did not exceed 30° C. When

the material had hardened the specimen was ground in such a way that the cut was placed parallel to and approximately 0.2 mm above the gingival face of the specimen. The metallographic polishment was done with siliceous powder with a maximum grain-size of about 5 μ. Next, the specimen was etched for about 10 seconds with 30 % nitric acid.

The corners of the preparations were photographed both in polished and in etched condition, the polished preparations by means of Leitz Opak-Illuminator with a true magnification of the negative of 35 times, the unetched preparations by means of Leitz Ultropak with a true magnification of 47 times.

The negatives of the polished, unetched preparations were used for quantitative determination of the porosity by the point counter method, while the etched preparations were used for quantitative determination of the gamma-phase by the same method.

The point counter method was applied as follows: The negatives were projected on a white screen, at right angles to it, so that the resulting image was 450 times as large as the amalgam preparation. On the screen was also placed a segment of a quadratic net (lines on a clear celluloid screen or points on white paper forming a quadratic pattern). The net segment formed a right-angled isosceles triangle, and was placed on the image of the preparation as shown in Figure 4, i.e. so that the surface roughness of the amalgam was included in the porosity. The two equal sides of the triangular segment had a length of 180 mm corresponding to a true lengh of the amalgam preparation of 0.4 mm. For each preparation corner in the triangular net a total number of 861 points was counted. Based on these counts calculations were made of the percentage porosity and the percentage content of gamma-phase in all the corners studied.

Three specimens were prepared for each combination of variables (see the next section), which permitted counting of 12 corners in all. In the tables presented in the following sections the results are therefore expressed as the mean value with standard deviation for 12 calculations of the percentage content of porosities and gamma-phase, so that each mean value in the tables represents 10332 (12×861) single preparation diagnoses.

The counting was carried out by one laboratory assistant (Miss

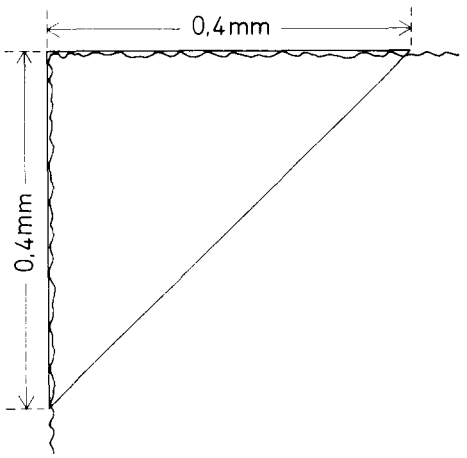

Fig. 4. The relative position of the triangular counting screen and the projected image of amalgam margin. The two equal sides of the screen were 180 mm long, and covered the projected image of 0.4 millimeter amalgam margin.

I. Christiansen). The diagnostic accuracy was very great in all cases. A randomely selected picture of porosities was counted 10 times, dismounting and remounting the screen between each count. The 10 counts gave a mean value of 22.46 % with a standard deviation of 0.24 %. In the same way the gamma-phase was counted 10 times in a picture with the result 15.68 ± 0.29 %.

RESULTS

The variables under the following points were used in studying the structure of the amalgam margins.

Table I

Marginal structure 0.2 mm from the cavity floor. Standard technique. Porosity and gamma-phase are expressed in volume %

Condenser	Condensation pressure 0.5 kg		Condensation pressure 2.0 kg	
	Porosity	Gamma-phase	Porosity	Gamma-phase
a	41.8 ± 22.3	2.8 ± 2.0	10.8 ± 4.1	8.8 ± 2.4
b	36.4 ± 18.0	1.4 ± 2.8	21.6 ± 7.9	7.2 ± 1.5
c	23.7 ± 8.4	7.8 ± 4.3	13.7 ± 5.9	11.7 ± 3.7
d	18.0 ± 6.0	7.0 ± 3.5	14.7 ± 3.8	12.7 ± 2.9
e	14.9 ± 11.4	8.2 ± 3.6	11.1 ± 4.9	8.8 ± 2.5
f	29.3 ± 12.2	6.5 ± 1.9	15.6 ± 4.7	10.8 ± 3.1

Table II

Marginal structure 1.5 mm from the cavity floor. Standard technique. Porosity and gamma-phase are expressed in volume %

Condenser	Condensation pressure 0.5 kg		Condensation pressure 2.0 kg	
	Porosity	Gamma-phase	Porosity	Gamma-phase
b	23.5 ± 16.6	3.9 ± 2.6	11.1 ± 3.1	9.0 ± 3.0
e	17.9 ± 8.1	2.7 ± 1.6	7.8 ± 4.7	11.2 ± 3.6

1. Type of plugger and magnitude of condensation pressure. In connection with the standard technique described above the following pluggers were used:

a. Pear-shaped condenser 1.2 mm in diameter
b. Pear-shaped condenser 2.0 mm in diameter
c. Circular, flat, smooth condenser 1.2 mm in diameter
d. Circular, flat, serrated condenser 1.2 mm in diameter
e. Square, flat, smooth condenser with an edge of 1.1 mm
f. Square, flat, serrated condenser with an edge of 1.1 mm.

Condensation pressures of either 0.5 kg or 2.0 kg were used. The results appear in Table I.

2. The position of the section above the cavity floor. To find out whether the distance from the cavity floor had any influence upon the structure of the amalgam margins some preparations were studied at a distance of 1.5 mm (instead of the conventional 0.2 mm) from the cavity floor. The results appear in Table II.

3. Effect of mercury content on the marginal structure. The

Table III

Marginal structure 1.5 mm from the cavity floor. The Eames' technique. Porosity and gamma-phase are expressed in volume %

Condenser	Condensation pressure 0.5 kg		Condensation pressure 2.0 kg	
	Porosity	Gamma-phase	Porosity	Gamma-phase
a	18.7 ± 9.9	9.8 ± 2.7	12.5 ± 4.8	11.8 ± 3.5
b	32.0 ± 15.4	11.1 ± 2.9	14.5 ± 5.1	15.3 ± 6.3
c	22.5 ± 6.4	10.2 ± 4.0	11.3 ± 6.7	14.4 ± 3.3
d	22.0 ± 13.6	7.8 ± 2.6	6.7 ± 4.5	15.0 ± 2.8
e	21.2 ± 8.9	9.0 ± 1.9	11.2 ± 6.4	14.2 ± 2.6
f	16.5 ± 6.7	7.6 ± 3.3	6.3 ± 2.7	12.7 ± 3.3

Table IV

Marginal structure 1.5 mm from the cavity floor. The Eames' technique. Condensation pressure 2.0 kg.

Amalgam specimens prepared by	Condenser	Porosity vol. %
I	c	8.3 ± 4.4
	d	7.9 ± 4.7
S	c	10.1 ± 5.3
	d	13.4 ± 5.3

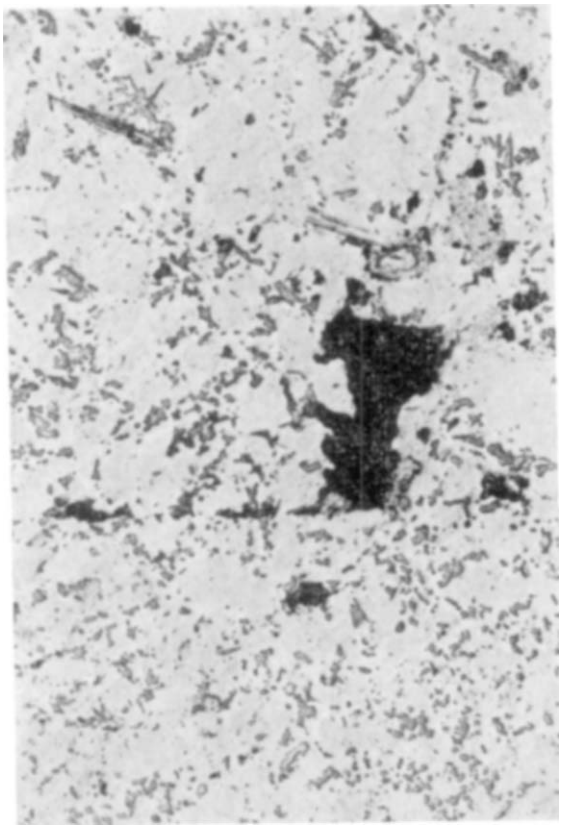

Fig. 5. Vertical section of specimen at the junction zone between two increments. Note the relatively high porosity at the bottom of the upper increment. Leitz Opak-Illuminator. × 240.

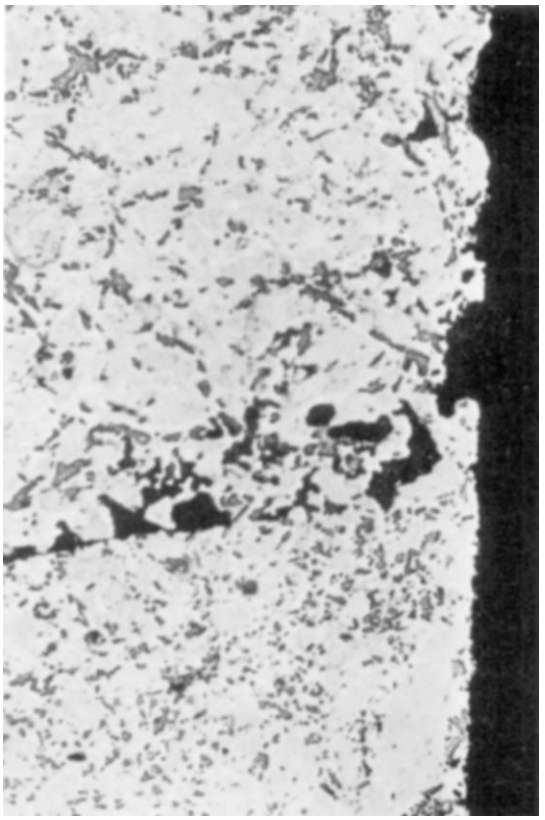

Fig. 6. As Fig. 5. Large, easily recognizable, γ_2-grains at the bottom of the upper increment indicating a relatively high amount of mercury. On the right, poor adaptation (large surface roughness) of the upper increment to the wall of the mold. Leitz Opak-Illuminator. × 240.

amalgam was mixed with a content of 48 % Hg and no mercury was expressed outside the cavity (The Eames' technique). The specimens were examined at a distance of 1.5 mm from the cavity floor. The results are given in Table III.

4. Influence of the individual factor on the experimental data. A few of the test groups under point 3 were reproduced by two co-workers with dental education and thoroughly familiar with amalgam techniques and dental material research. The results appear in Table IV.

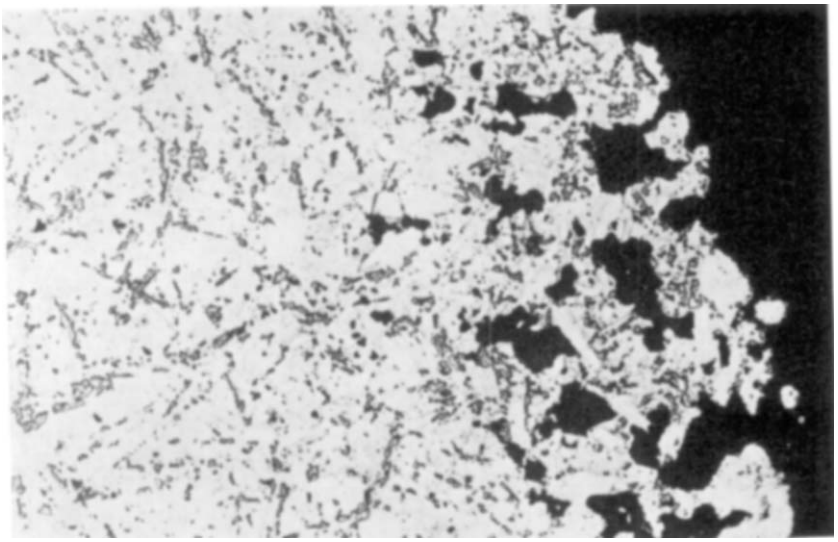

Fig. 7. Section of undivided amalgam mix with 58 % mercury. Note the large γ_2-grains and the lack of porosity; to the right, the only slightly roughned free surface. Leitz Opak-Illuminator. × 150.

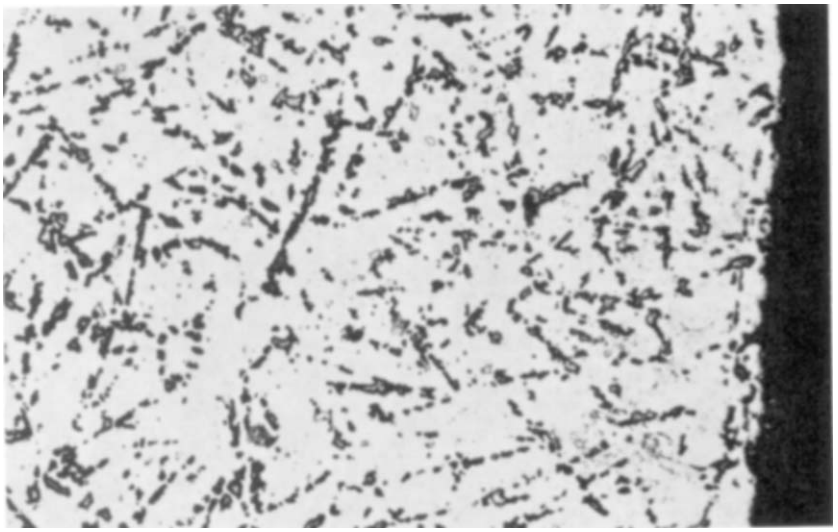

Fig. 8. Piece taken from amalgam mix with 58 % initial mercury content, reduced to 48 % by expression before division. Note the relatively small γ_2-grains and the extremely porous and rough surface layer. Leitz Opak-Illuminator. × 150.

5. Vertical sections of a number of specimens prepared by conventional technique or the Eames' technique using different condensation pressures and pluggers, displayed in almost every case distinct lamination under the microscope (Figures 5 and 6). The upper part of each condensed increment was relatively lacking in porosity, while the lower part of each increment was badly porous, in particular near the sides of the mold. Further studies of the structure of the various amalgam mixes and of pieces taken from these gave the following results:

a. Whole mix with 58 % Hg: the amount of porosity very slight (below 0.1 %), the surface faintly rough (Fig. 7).

b. Piece from mix with 58 % Hg: as a, when division followed immediately after trituration; with delayed division the structure assumed more and more the appearance described under d.

c. Whole mix with initial 58 % Hg, reduced to 48 % by expression through a squeeze cloth: the porosity very low (less than 0.1 %), the surface slightly rough (as under a).

d. Piece from c: the porosity slight in the central part, the surface layer very porous and rough (Fig. 8).

e. Whole mix with 48 % Hg: the porosity in the central part moderate (about 2 %), the surface layer very rough.

f. Piece from e: the porosity in the central part moderate (about 2 %), the surface layer as under d, very porous and rough.

These observations contribute to account for the consistently high porosity of the amalgam specimens mentioned under points 1—4. It must also be remembered that prior to condensation each increment was broken up into even smaller fragments resulting in increased porosity of the condensed amalgam.

The consistent, though far from complete elimination of the porosity with an increase of the condensation pressure from 0.5

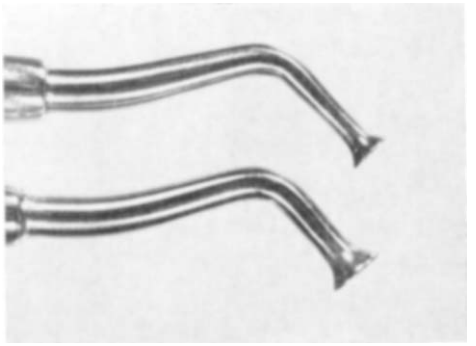

Fig. 9. Amalgam condenser with concave neck used in preparation of specimens by wet technique.

to 2.0 kg (see Tables I—III) shows how difficult it is to eliminate structural defects once they have been incorporated in the amalgam.

The observations under points a—f led to a modification of the traditional technique in the following respects:

A. In view of the observations under a and b no mercury excess was expressed during condensation of the amalgam into the cavity.

B. To avoid as far as possible that surface defects of the increments (cf. b with reference to d) should act as air-traps during condensation of the amalgam, no mercury excess was removed from the cavity after condensation of each increment, unless the thickness of the film of expressed mercury was over approximately 1/4 mm.

Traditional technique with the modifications A and B will be termed "wet technique".

Packing was done exclusively with flat, smooth-faced pluggers, since the pear-shaped points were more apt to penetrate the amalgam than the flat pluggers, and the grooves in the serrated pluggers were unnecessary. The pluggers were given the following designations:

g. Circular, diameter 3.0 mm*)
h. Circular, diameter 2.5 mm
i. Circular, diameter 1.8 mm
k. Circular, diameter 1.3 mm
l. Square, edge length 2.2 mm
m. Square, edge length 1.5 mm
n. Square, edge length 1.1 mm.

To prevent penetration specimens to be condensed with the two smallest pluggers (k and n) were precondensed with a larger one (i) under rather light pressure.

The results of the tests appear in Table V. Figures 10 and 11 show characteristic structures of amalgam margins with different degrees of porosity and contents of gamma-phase.

Vertical sections of specimens prepared by wet technique with pluggers k, m, and n, and with a condensation pressure of 2 kg showed no lamination as regards the distribution of either porosities or phases. Special experiments with specimens prepared by wet technique, and exclusively with plugger k and a 2 kg pressure, demonstrated that it was possible to avoid lamination provided the thickness of the fully condensed layer did not exceed 0.6 mm (non-preamalgamated alloys) and 0.9 mm (preamalgamated alloys), respectively.

Table V

The marginal structure 1.5 mm from the cavity floor. Wet technique. Porosity and gamma-phase are expressed in volume %. Condensation pressure 2.0 kg.

Condenser	Porosity	Gamma-phase
g	6.4 ± 3.2	3.5 ± 1.3
h	5.8 ± 2.2	5.6 ± 2.1
i	2.8 ± 1.4	9.2 ± 1.9
k	1.3 ± 0.9	11.1 ± 2.0
l	2.9 ± 1.8	7.3 ± 3.4
m	1.3 ± 0.8	8.5 ± 3.0
n	1.2 ± 0.8	10.6 ± 2.1

*) Instruments g—k with concave neck (Fig. 9) proved to be useful for removal of excess mercury, and gave amalgam margins of the same structure as instruments without concavity.

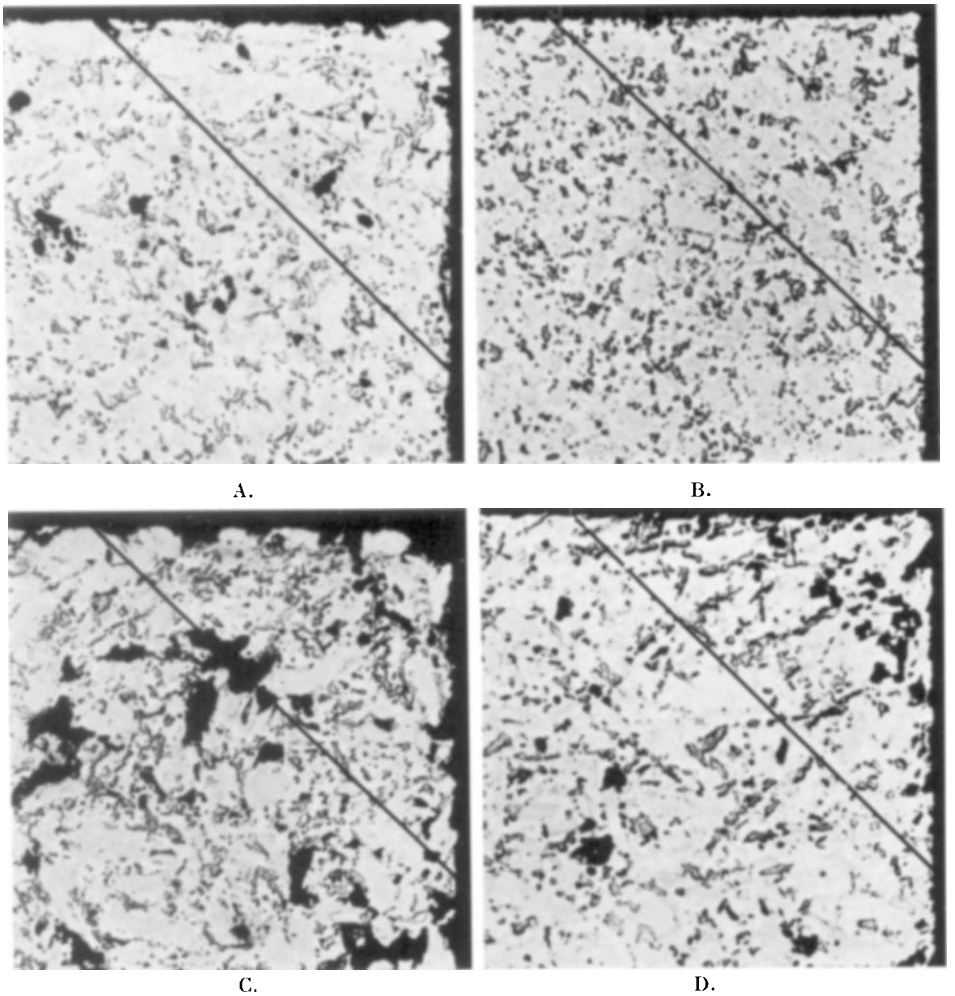

Fig. 10. Horizontal sections of specimens 1.5 mm from the bottom of the mold. The black line delimits the triangular area which was quantitatively analyzed for porosity and γ-phase. A. 15.8 % porosity. B. 8.5 % porosity. C. 4.3 % porosity D. 1.2 % porosity. Note the decidedly better adaptability in D (wet technique) than in, for example, A and B (traditional technique). Leitz Opak-Illuminator. × 120.

Throughout the investigation efforts were made to randomize the sequence of the experimental series. Even so, complete randomization of the order in which the series were carried out was not possible. Therefore a number of completely randomized speci-

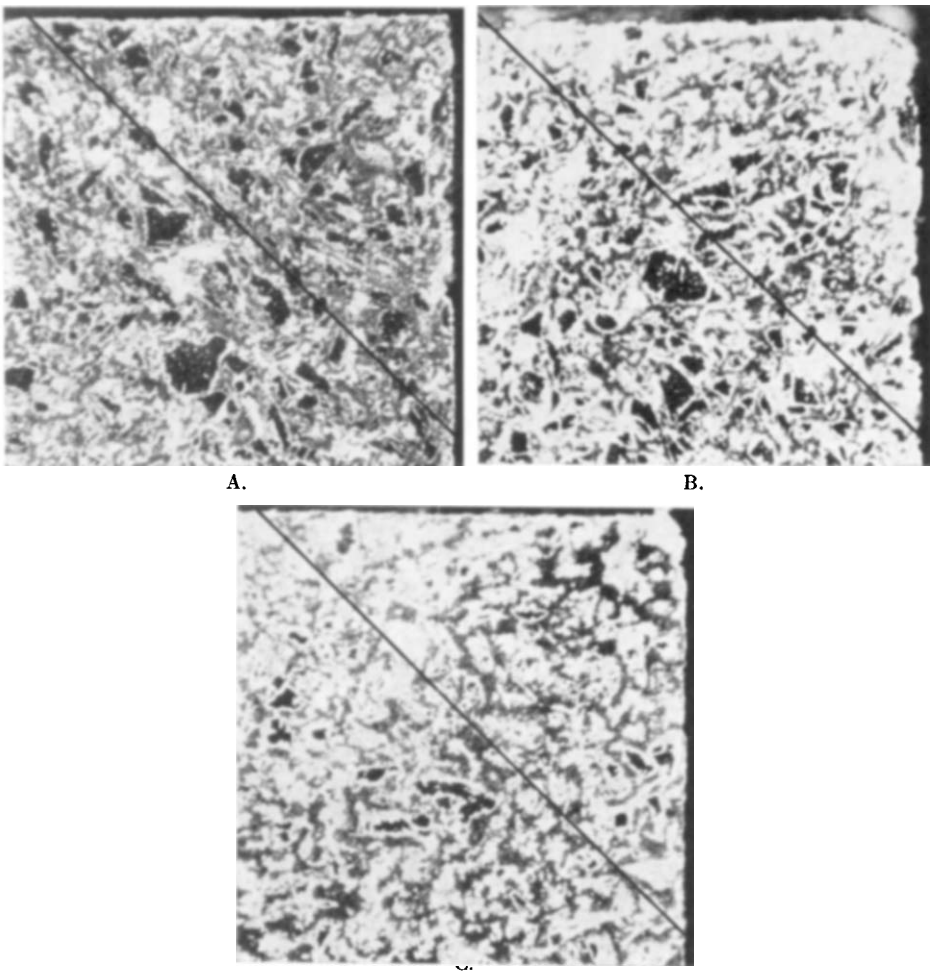

Fig. 11. Horizontal sections of specimens 1.5 mm from the bottom of the mold. The black line bounds the triangular area analyzed for porosity and γ-phase. A. 15.2 % γ-phase. B. 10.1 % γ-phase. C. 2.4 % γ-phase, Leitz Ultropak. × 150.

mens representing the various series was prepared, both during and after the investigation. These specimens showed no deviations from those on which the report is based.

Further, specimens representing the various test groups were made with different alloy brands. The structure of these specimens was not measured quantitatively, but microscopic exami-

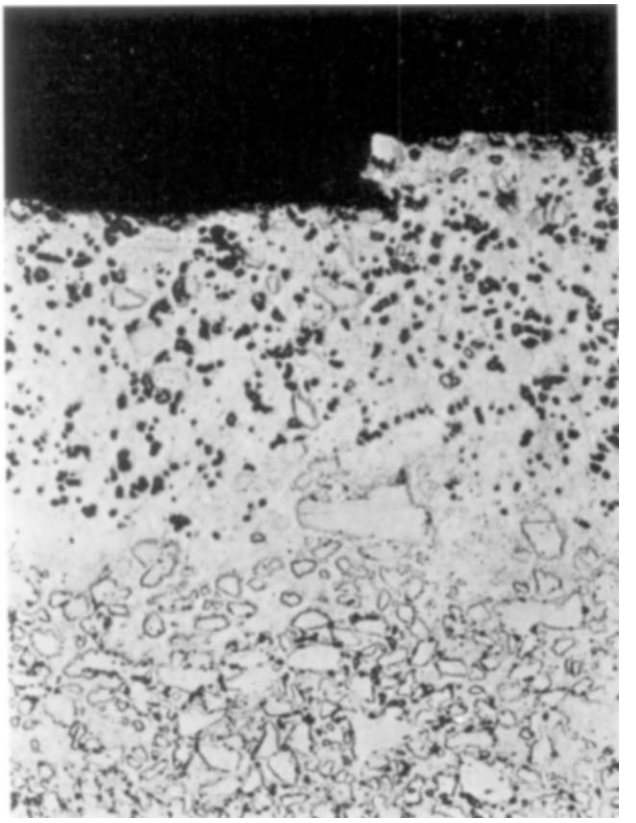

Fig. 12. Relief polished section of the upper part of an amalgam specimen prepared by wet technique. At the bottom: well-condensed amalgam; at top: expressed mercury excess containing sufficient alloy for setting. Leitz Opak-Illuminator. × 120.

nation revealed the same fundamental relations as reported for True Dentalloy used in the principal investigation. It should be added that with wet technique the preamalgamated alloys were mixed with 55 % mercury and with the Eames' technique with 43 % mercury allowing for the smaller amounts of mercury required with these brands.

Finally, the bottom corners (bounded by the bottom of the mold and two adjacent sides) of a number of specimens were examined in order to find out, whether the wet technique would give an improvement in structure as compared to the conven-

tional technique and the Eames' technique. The specimens were cut in a plane at right angles to the bottom face and diagonally through this face. Inspection (without measurements) revealed the same structural characteristics as found for the horizontal sections 1.5 mm from the bottom of the mold.

Figure 12 shows a strongly reliefpolished, unetched section of a specimen obtained by wet technique with a film of expressed mercury excess, about 0.2 mm in thickness, left on top of condensed amalgam. The well-defined boundary between the two structures, and the high concentration of gamma-phase in the condensed amalgam, illustrates that it is well possible to obtain effective condensation of amalgam covered with a relatively thick layer of mercury excess. Examination of several other preparations of the same type have shown that this picture is representative.

In studying the porosity of the specimens it was observed that the lower the findings for porosity was, the better was, in general, the adaptation of the amalgams to the walls of the steel mold. Specimens obtained by wet technique invariably showed better adaptation than those obtained by traditional technique or the Eames' technique (cf. Figure 10).

DISCUSSION

The data grouped under the various points give rise to the following comments:

re point 1. The specimens display in all cases very high marginal porosity, as a whole somewhat more intense at the 0.5 kg condensation pressure than at 2.0 kg. Only in a few groups is the gamma-phase content higher than 10 %. The structure is, on the whole, so poor in all the groups that a closer analysis of the data seems without interest.

re point 2. The position of the section (the distance from the cavity floor) seems to have little influence on the structure of the amalgam margins, which also must be described as very defective at this higher level.

re point 3. The results for this series are very similar to those under the two preceding points. The amount of gamma-phase is somewhat larger (the difference is statistically significant) in

margins prepared by the Eames' technique) than in margins prepared by traditional technique. The porosity is again very pronounced, although it shows a tendency toward reduction at the 2.0 kg condensation pressure and by use of the two serrated condensers d and f. However, amalgam with 6—7 % porosity is far from possessing maximum properties (*Jørgensen & al.*, 1966).

re point 4. The results of these control tests indicate that the individual factor does not appreciably interfere with the experimental findings. Nor was it possible otherwise to find anything suggesting that the findings were affected by any personal factor or not reproducible. The relatively high standard deviations scarcely reflect insufficient standardization of the technique, but rather a quality inherent in it.

re point 5. The wet technique enables preparation of amalgam specimens with definitely lower porosity and better adaptation than specimens prepared by either conventional or the Eames' technique. Moreover, the content of gamma-phase is relatively high (about 10 %). Previous studies (*Jørgensen & al.*, 1966)*) have established that the wet technique produces specimens with considerably higher crushing strenght than comparatively dry techniques.

With regard to conformity of the condenser point with the right-angled corners of the mold, a comparison between condensers k and n in Table V shows that a small circular condenser has the same effect as a square one with the same end face area. Only with larger condensers is better condensation achieved with square than with round points. In practice, however, the final condensation can scarcely be done with larger condensers than k or n, so a round plugger may just as well be used as one with a square face or otherwise designed on the principle of conformity.

CONCLUSIONS

The structure of the vertical margins of amalgam specimens representing Class II fillings can be essentially improved by use

*) Studies, as yet unpublished, have shown that wet technique amalgam exhibits much less delayed expansion than amalgam prepared by conventional technique or the Eames' technique.

of the so-called wet technique instead of traditional or the Eames' techniques. The wet technique is characteristic in that the amalgam has a relatively high mercury content when introduced into the cavity, and in that, following careful condensation of each increment, no mercury is removed from the cavity unless it forms a film not less than approximately 1/4 mm thick on top of the condensed amalgam. The improvement in structure is manifested by a radical reduction of the porosity at the same time as the amount of gamma-phase is relatively large. The wet technique is further characterized by a material improvement in the adaptability of the amalgam.

Complete conformity between condenser point and a right-angled corner in the mold (the cavity) is not necessary for effective condensation.

SUMMARY

The present work is a study of the structure of the vertical margins of amalgam specimens of the same type as the proximal part of Class II fillings.

A modification of the point counter method was applied in the quantitative investigation of the structure of metallographic micropreparations of the amalgam. The results are based on approximately 3/4 million single diagnoses of the structure of amalgam specimens.

Amalgam margins, carefully condensed by traditional technique or by the Eames' technique were in all cases very porous; with a modified technique (so-called wet technique) is it possible almost completely to eliminate the porosity, to improve the adaptability to the cavity walls, and to reduce the mercury content of the condensed amalgam to a relatively low and constant level.

The reduction of porosity is of particular importance for the strength and for the resistance to corrosion of the amalgams.

Small condensers with circular point are just as effective as small condensers with square point for condensation of amalgams into right-angled corners.

RÉSUMÈ

STRUCTURE DES BORDS DES OBTURATIONS D'AMALGAME DE CLASSE II.

L'auteur a étudié la structure des bords verticaux d'éprouvettes d'amalgame de même type que la partie proximale d'obturations de classe II.

Pour l'étude quantitative de la structure de l'amalgame, une modification de la méthode "point counter" a été utilisée sur des préparations microscopiques métallographiques; les résultats sont basés sur environ 750.000 déterminations individuelles de la structure des amalgames.

Lorsque l'amalgame est condensé soigneusement suivant la technique traditionnelle ou suivant la technique d'Eames, les bords sont dans tous les cas fortement poreux; mais si l'on utilise une technique modifiée ("technique mouillée"), il est possible d'éliminer presque entièrement les porositées et déaméliorer l'adaptibilité aux parois de la cavité, en même temps que la teneur en mercure de l'amalgame condensé se trouve résuite à un niveau relativement bas et constant.

La réduction de la porosité a une importance particulière pour la solidité des bords et pour la résistance de l'amalgame à la corrosion.

ZUSAMMENFASSUNG

DIE KANTENSTRUKTUR IN AMALGAMFÜLLUNGEN 2. KL.

Die Struktur der vertikalen Kanten von Amalgamversuchskörpern gleichen Typs wie der approximale Teil von Füllungen 2. Kl. ist untersucht worden.

Bei der quantitativen Strukturuntersuchung wurde eine Modifikation der point counter Methode an metallographischen Mikropräparaten des Amalgams angewandt; die Ergebnisse basieren auf ca. 3/4 Millionen Einzeldiagnosen der Struktur der Amalgame.

Wird das Amalgam nach traditioneller Technik oder Eames Technik sorgfältig kondensiert, so werden die Kanten in allen Fällen stark porös; wendet man dagegen eine modifizierte Technik (nasse Technik) an, ist es möglich, die Porosität fast ganz

zu eliminieren und die Adaptabilität an die Kavitätenwände zu verbessern, während gleichzeitig der Quecksilbergehalt des kondensierten Amalgams auf ein relativ niedriges und konstantes Niveau herabgebracht wird.

Die Reduktion der Porosität ist von besonderer Bedeutung für die Kantenstärke und für die Korrosionsresistenz des Amalgams.

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