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BOND STRENGTH OF REPAIRED AMALGAM

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INTRODUCTION

Previous studies on repair of amalgam fillings have shown that the bond strength of repaired amalgam often is considerably lower than the strength of unrepaired amalgam.

Terkla et al. (1961) found that the flexural strength of amalgam bonds always is less than half the flexural strength of unrepaired amalgam. *Kirk* (1962) demonstrated that the repaired area has a tensile strength which often is much lower, though sometimes almost as high as that of unrepaired amalgam.

In neither study a detailed analysis has been made of possible factors in the strength of the bond between old and new amalgam, and no method for obtaining maximum bond strength has been proposed.

The present investigation was designed 1) to analyse some factors in the amalgam technique which are likely to influence the strength of the bond between old and new amalgam, and 2) to analyse to what extent the structure of the old amalgam is affected by excess mercury flowing over its free surface during the repair.

The first part of the study is based on the consideration that establishment of a union between old and new amalgam is, in principle, comparable to soldering, and that a condition for good bond strength is an effective wetting of the solid alloy (the old amalgam) with the liquid (mercury with dissolved alloy components).

MATERIALS AND METHODS

The investigation was carried out with True Dentalloy (S.S. White Dental Mfg. Co., G.B., batch no. 926503) and mercury (May & Baker Ltd., G.B., batch no. R 165) certified to meet the requirements of the F.D.I. specification no. 2.

Alloy and mercury were proportioned in the ratio of 1.24/1.86 g and mixed for 20 seconds in a Wig-L-Bug with pestle in the plastic capsule. Two minutes after the mix was completed the amalgam was condensed into a cylindrical steel mold of 5.00 mm diameter using steel pistons about 0.01 mm smaller in diameter than the mold. The condensing force was 40 kp, and the condensation time three minutes. The finished test specimens contained 48.0 $\pm$ 0.5 % mercury, and had a length of 10.0 $\pm$ 0.5 mm.

A. The specimens were randomely divided into a control group and an experimental group and stored at room temperature (23 $\pm$ 2° C). Seventy-two hours after preparation the flexural strength of the control specimens was measured by means of an apparatus designed as illustrated in Fig. 1. The apparatus was mounted in a Losenhausen testing machine, which loaded the specimens at a rate of 1 kp/sec.

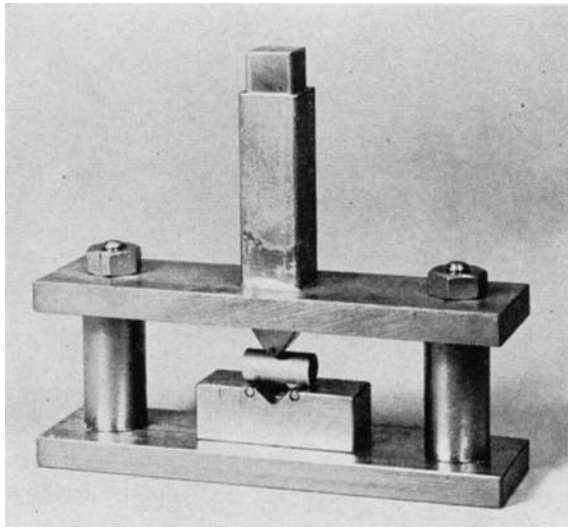

Fig. 1. Apparatus for mounting of test specimens to be measured for flexural strength. The loading bar and the supports are 1,5 mm in diameter, and the two latter rods placed 7.0 mm apart.

Just under 72 hours from preparation the specimens in the experimental group were sawn through to form two cylinders, each with a length of 5.0 ± 0.5 mm. The cut end surfaces were polished with carborundum paper no. 600, rinsed in water and ethanol and dried. After varied treatment of the end surfaces (see below) the 5 mm long specimens were placed in the cylindrical molds with the conditioned surfaces upwards. Against these surfaces freshly mixed amalgam was condensed by the same technique as described above using, however, only half as much amalgam as for the original specimens. Thus the repaired specimens became 10.0 ± 0.5 mm long. As shown by earlier experiments the variable introduced (the amount of the mix) does not produce detectable changes in the properties of the specimens (mercury content, compressive strength, setting expansion).

The repaired specimens were measured for flexural strength 72 hours after the repair in the same way as the control specimens.

After polishing, cleaning and drying, and before the repair, the end surfaces of the 5 mm long experimental specimens were treated in one of the following ways:

1. No additional pre-treatment. The amalgam used for the repair was packed against the end surface immediately after cleaning and drying.

2. The end surface was wetted with saliva and dried and the repair amalgam condensed against it immediately after the treatment.

3. The specimen was kept at room temperature for 48 hours before the repair, so that a slight oxidation of the amalgam surface might be expected. The oxidation was not visible to the naked eye, but microscopic inspection of the polished amalgam surfaces revealed distinct oxidation after 48 hours.

4. The end surface of the specimen was wetted with mercury by grinding under light pressure for about 10 seconds on carborundum paper no. 600 in the presence of a drop of mercury.

5. The end surface was wetted with mercury by 10 seconds intensive scrapping with the edge of a plugger in the presence of a drop of mercury.

Ten specimens were tested in the control group and in each experimental group. In addition, a small number of specimens for each of the five test groups was prepared for microstructural study of the repaired area.

B. The effect of the age of the original amalgam upon the strength of the repair was investigated in a special series. Before the repair the original amalgam was stored at room temperature for 48, 72, or 720 hours, respectively, and the end surfaces of the subsequently halved specimens treated by the above described method 4. The flexural strength was measured on ten specimens in each age group 72 hours after the repair.

C. The significance of the age of the bond was also studied in a special series. The cut surfaces of the halved specimens were treated by method 4 before repair. The gain in strength with the time elapsed from the repair was compared with the gain in strength of the non-repaired control specimens. Ten specimens were tested in each age group of both repaired and unrepaired specimens.

To supplement the abovementioned tests on mechanically condensed specimens a small number of hand-condensed specimens was measured for strength, both in unrepaired and in repaired condition. The experimental results did not deviate fundamentally from those obtained by mechanical condensation.

D. In the investigation on a possible structural change in the old amalgam due to excess mercury flowing over its free surface at the time of repair all the specimens were packed by hand. The amalgam was packed by different techniques into circular cavities (diameter 4 mm, depth 3 mm) in Plexi glass. Seventy-two hours after preparation one half of each filling was removed with a fissure bur, leaving a semi-circular cavity with one of its walls consisting of amalgam. This new cavity was immediately filled with freshly mixed amalgam following the technique used for the primary filling. The excess mercury expressed from the initial increment of repair amalgam after introduction into the cavity was rubbed into the wall of old amalgam with the edge of the plugger. The rubbing lasted 5—10 seconds, and apparently caused the old amalgam surface to be thoroughly wetted with mercury. After condensation part of the expressed mercury had flowed over the free surface of the primary amalgam filling. This excess was at once removed by dabbing with a small sample of unset, dry amalgam.

After about three days the repaired fillings were cut through at right angles to the free filling surface and at the boundary between old and new amalgam. The cut surface was then polished metallographically and its structure examined under the microscope, both in polished and in etched condition.

RESULTS

A. The significance of the surface treatments of the amalgam before the repair is shown in Table I.

The flexural strength in the table is indicated by the force required to break the specimens. Groups 1—5 refer to the abovementioned treatments of the end surfaces. The figures represent mean values and standard deviations. It is evident from the table that the repaired specimens were materially redu-

Table I

Flexural strength of repaired amalgam

N = 10

Surface treatment	Control	1	2	3	4	5
Flexural strength kp	105.9±5.1	48.3±6.8	17.8±3.2	22.0±5.2	103.4±5.0	95.7±6.2
Flexural strength %	100	45.6	16.8	20.8	97.6	90.3

ced in strength as compared to the unrepaired specimens (column 1, 2 and 3), unless the repair surface was rubbed and wetted with mercury. If this was done, the strength values for the repaired specimens were equal, or nearly equal, to those for the unrepaired specimens. The difference between the control group and group 4 was not statistically significant (t = 1.107). The difference between the control group and group 5, on the other hand, was highly significant (t = 4.017).

All the specimens in groups 1, 2 and 3 fractured at the joined surfaces, which as a rule showed only faint signs of union. In groups 4 and 5, on the other hand, the fractures were most frequent outside the junction, and whenever they were localized to the junction the two amalgam surfaces showed

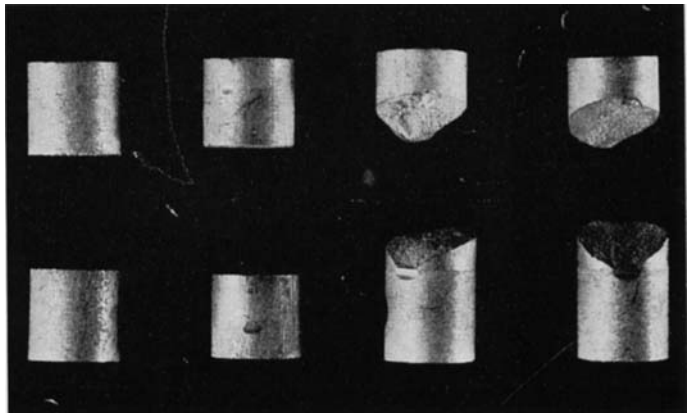

Fig. 2. Fractured repaired specimens. Left, two specimens where the surface to be bonded was contaminated with dried saliva. Right, two specimens where the surface was wetted with mercury by grinding on carborundum paper No. 600.

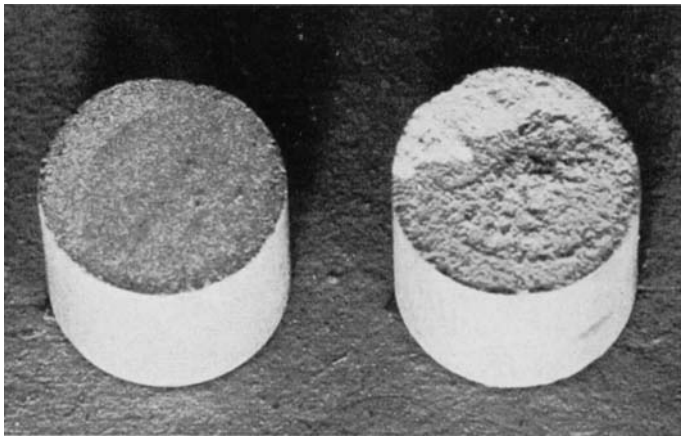

Fig. 3. Fracture of two repaired specimens. The surface to the left had been contaminated with dried saliva before the repair, while the surface to the right had been wetted with mercury by grinding on carborundum paper No. 600.

always clear signs of union (Figs. 2 and 3). These observations correspond well with the examination of the microstructure in the repaired area, which showed a well-defined boundary between old and new amalgam in groups 1, 2 and 3 (Fig. 4). The boundary was the result of an accumulation of voids and of the relatively weak γ_2-phase disposed immediately on top of the surface of the old amalgam in a 5—10 μ broad zone. Such a boundary zone was either unrecognizable or very little pronounced in the specimens from group 4 and 5 (Fig. 5).

B. The influence of the age of the original amalgam upon the strength of the bond is demonstrated in Table II.

A statistical analysis of the findings shows that the age of the original amalgam is without influence upon the strength of the repair.

C. The effect of the age of the repaired area upon the flexural strength is demonstrated in Table III, which also shows the strength for the control group.

Table II

Effect of the age of the original amalgam upon the flexural strength of the repaired amalgam

N = 10

Age of original amalgam in hours	48	72	720
Flexural strength kp	105.1±4.6	103.4±5.0	104.0±6.2

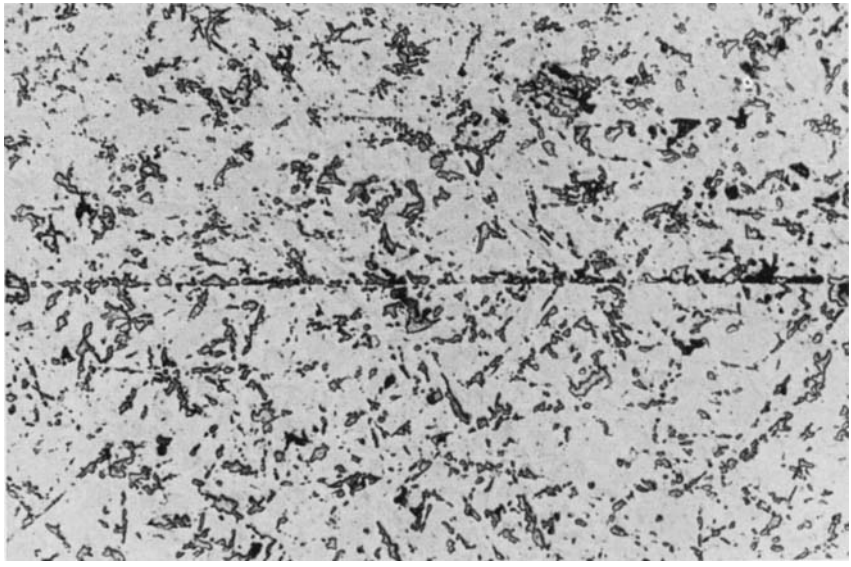

Fig. 4. Structure in the boundary zone between old (lower) and new (upper) amalgam. The old amalgam had been contaminated with dried saliva before the repair. × 120.

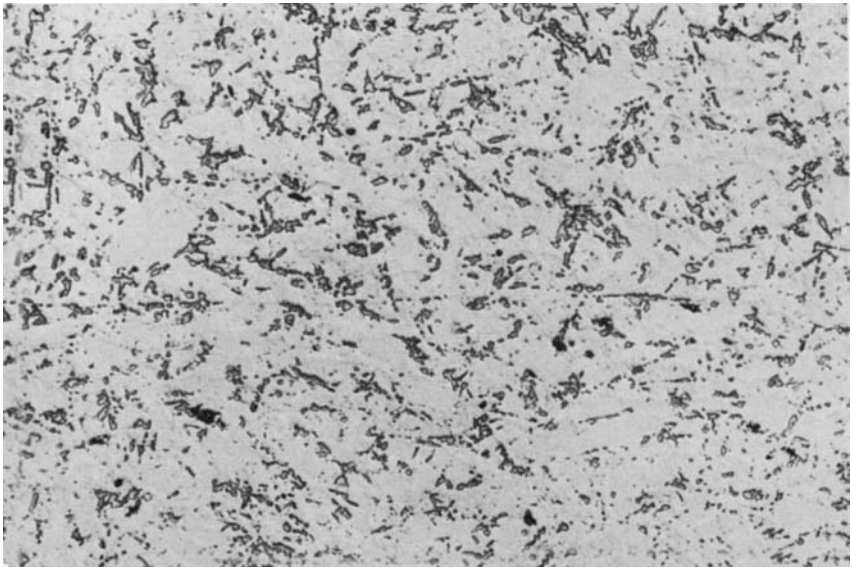

Fig. 5. Structure in the boundary zone between old (lower) and new (upper) amalgam. The old amalgam had been wetted with mercury by grinding on carborundum paper No. 600 before the repair. × 120.

Table III

Effect of the age of the bond upon the flexural strength of the repaired amalgam

N = 10

Age in hours	Strength of the repaired area in kp	Strength of the control specimens in kp
1	12.1±1.9	30.2±2.6
2	15.8±2.0	48.0±3.6
4	23.1±1.8	59.4±4.2
8	34.6±3.0	74.3±3.8
16	60.2±8.8	94.0±4.2
24	90.8±7.9	102.9±3.3
72	102.6±6.0	103.4±5.0
168	100.2±7.5	101.9±5.1

The data in Table III are diagrammed in Fig. 6. The diagram shows that the strength of the unrepaired amalgam increased proportionally to the logarithm of the age of the amalgam until 24 hours, where the setting reaction must be supposed to be completed. If the lower curve is plotted in a co-ordinate system with arithmetic abscissa the curve will assume a right line until 24 hours. The difference between the two curves shows that the process leading to the setting of the amalgam was fundamentally different from the process

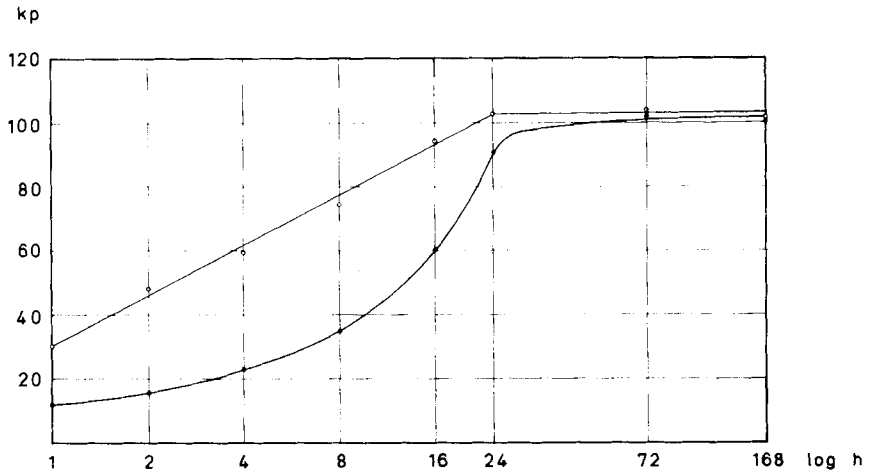

Fig. 6. Increase in flexural strength of setting amalgam (upper curve) and of repaired amalgam (lower curve) in relation to time. The strength is expressed as the force necessary to break the test cylinders.

underlying the union between old and new amalgam. It is characteristic that the setting process proceeds faster for the first eight hours than the repair process, while the latter becomes the faster during the following period. After about 24 hours there is no longer any difference between unrepaired and repaired amalgam.

D. The structure of the free, set amalgam surfaces, which for a short time were covered with excess mercury expressed in condensation (see above), proved to be unchanged, both qualitatively and quantitatively.

DISCUSSION

The experimental results show that it under certain conditions is possible to bond new amalgam to old amalgam without injuring the latter and to obtain almost the same strength of the bonding zone as of unrepaired amalgam. From a materials point of view it should therefore be considered good clinical practice to combine set amalgam fillings with new amalgam in cases of a need for repair or extension of the former. This result is inconsistent with the traditional but unsubstantiated conception that new amalgam should never be combined with old amalgam.

SUMMARY

Investigations have been made on the effect of several factors upon the bond strength of repaired amalgam. The investigations showed the following results.

1. The bond strength of repaired amalgam is almost the same as the strength of unrepaired amalgam if the repair surface was effectively wetted by mercury immediately before the repair. An effective wetting was obtained by rubbing the clean repair surface in mercury on fine carborundum paper or by scraping the surface with the margin of an amalgam plugger in the presence of mercury.

2. The age of the old amalgam, once it has set, had no influence upon the strength of the repair.

3. During the first hours the bond strength of the repaired amalgam was increasing more slowly than the strength of a setting amalgam.

4. Excess of mercury flowing over the free surface of the old amalgam during the condensation of new amalgam did not visibly change the structure of the former if the mercury excess was removed by absorbing it into unset, dry amalgam.

RÉSUMÉ

RÉPARATION DE L'AMALGAME

La réparation de l'amalgame a fait l'objet de recherches concernant plus particulièrement l'importance de divers facteurs sur la solidité de la réparation. Cette étude a mis en évidence les résultats suivants:

1. L'amalgame réparé atteint une résistance à peu près aussi grande que l'amalgame non réparé, à condition que l'ancien amalgame ait, avant la réparation, été »mouillé» efficacement par du mercure au niveau de la surface à réparer. Pour cela, la surface à réparer doit être propre et on y appliquera du mercure en frottant avec du papier de carborundum à grain fin ou avec le bord d'un fouloir à amalgame.

2. Lorsque la prise de l'ancien amalgame est terminée, l'âge de l'amalgame n'a pas d'influence sur la solidité de la réparation.

3. Pendant les premières heures, la solidité de la réparation augmente plus lentement que ne le ferait normalement la résistance d'un amalgame pendant la prise.

4. L'excès de mercure coulant pendant la réparation sur les surfaces libres de l'ancien amalgame né détermine pas de modifications de la structure de cet amalgame si l'on a soin, immédiatement après la réparation, d'éliminer cet excès en le faisant absorber par de l'amalgame sec et n'ayant pas encore pris.

ZUSAMMENFASSUNG

REPARATUR VON AMALGAM

Es sind Untersuchungen vorgenommen worden über die Reparatur von Amalgam mit besonderem Hinblick auf die Bedeutung verschiedener Faktoren für die Stärke der Reparatur. Die Untersuchung ergab folgendes:

1. Repariertes Amalgam erreicht ungefähr die gleiche Stärke wie nicht repariertes Amalgam, vorausgesetzt, dass das alte Amalgam vor der Reparatur auf der Reparaturfläche effektiv mit Quecksilber befeuchtet wird. Eine solche Befeuchtung wird durch Einreiben von Quecksilber in die nicht verunreinigte Reparaturfläche mittels feinem Karborundumpapier oder mit dem Rand eines Amalgamstopfers erreicht.

2. Wenn das alte Amalgam abgebunden ist, hat sein Alter auf die Stärke der Reparatur keinen Einfluss.

3. Die Stärke der Reparaturstelle wächst in den ersten Stunden langsamer als die Stärke eines abbindenden Amalgams.

4. Quecksilberüberschuss, der während der Reparatur auf die freien Oberflächen des alten Amalgams läuft, ändert dessen Struktur nicht, wenn nur der Quecksilberüberschuss unmittelbar nach der Reparatur durch Aufsaugen in unabgebundenes, trockenes Amalgam entfernt wird.

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