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A MICROSCOPIC INVESTIGATION OF THE ADAPTATION OF SOME PLASTIC FILLING MATERIALS TO DENTAL CAVITY WALLS

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Earlier published measurements of the polymerization shrinkage and water-absorption expansion of plastic filling materials are often difficult to relate to the clinical application of the materials. In the present work an attempt has been made to rectify this situation. The following materials were investigated: Adaptic, Addent XV, Blendànt, Concise, D.F.R., Palakav, capsulated Palakav, TD 71, Palavit 55, Sevriton Simplified and Swedon. The filling materials were placed in cavities cut in extracted teeth. Dimensional changes of the fillings were measured in a microscope. The complete investigation was conducted in a thermostat room maintained at 37°C. The fillings were examined either shortly after initial set or after varying periods of immersion in water. Immediately after initial set a marginal gap at both the enamel and dentin levels of the walls was observed. Polishing the fillings at this time resulted in a zone of fractured enamel 20—40 microns wide. If the fillings were stored in water, the width of the marginal gaps was reduced; for some brands the gaps were completely closed in less than 32 days. Polishing of fillings with closed shrinkage gaps resulted in a minimum of fractures of the enamel margins.

It is universally recognized that all plastic filling materials shrink during polymerization, and that this is one of the unfortunate properties of this group of materials. Polymerization shrinkage gives rise to inferior adaptation to cavity walls, thus involving a risk of further damage both to the hard tissues and the pulp.

Numerous publications have been devoted to the subject of dimensional changes during the setting process such as *Gotfredsen* (1969), *Lee et al.* (1969), *Lockowandt & Stüben* (1952), *McLean* (1961) and *Smith & Schoonover* (1953). A feature shared by these works is, that they are based on measurements conducted on free test specimens. This opens up the possibility of achieving results which are conditional upon the methods of testing and which may be difficult or even impossible to apply in a clinical evaluation of

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the materials. *Gotfredsen* (1969) measured polymerization shrinkage of Addent 12 ® on a mercury surface. With this method it is inevitable that evaporation of monomer from the surface of the specimen occurs, which it is not possible to take into consideration. Objections (*Lockowandt & Stüben*, 1952) can also be directed at the dilatometer method used in determining the volumetric shrinkage of plastic materials (*Lee et al.*, 1969; *McLean*, 1961; *Smith & Schoonover*, 1953). Moreover, experiments with specimens do not permit one to determine how much of the shrinkage measured can be attributed to the clinically relevant wall-to-wall shrinkage, what is termed the effective shrinkage, and how much occurs as a subsidence of the free surface of the filling without any detrimental effect on adaptation.

To circumvent these difficulties *Asmussen & Jørgensen* (1971) based their study on measurements of the effective shrinkage of fillings made in accordance with a simulated clinical technic in extracted human teeth.

When plastic materials absorb water they expand. *Gotfredsen* (1969), *Smith & Shoonover* (1953) and others determined from disk-shaped specimens the total water-absorption expansion of a number of plastic filling materials. *Asmussen & Jørgensen* (1971) studied dimensional changes resulting from water-absorption on another basis, having determined the period of time that elapses before water-absorption has compensated for polymerization shrinkage.

The investigation of *Asmussen & Jørgensen* (1971) was carried out at room temperature. At oral temperature the effective polymerization shrinkage may differ from the shrinkage measured at room temperature because of a change in adhesion, setting time and viscosity of the plastic filling materials. Moreover, at oral temperature the time necessary for the water-absorption expansion to compensate for the polymerization contraction must be reduced as the rate of diffusion of water increases with temperature. The present work is based on the methods developed by *Asmussen & Jørgensen* (1971), with the exception that an even further approximation to the clinical situation has been attempted by conducting the complete investigation at 37°C.

MATERIALS AND METHODS

1. General. The adaptation to cavity walls of the plastic filling materials studied could be determined by a microscopic examination of polished fillings. Poor adaptation was illustrated by a gap between the tooth and the filling material. The microscopic inspection took place either immediately after the initial setting of the filling or after a time period of varying length

in which the filled teeth were deposited in demineralized water at 37°C. Immediately after initial setting, a gap could be measured and taken as an expression of the effective polymerization shrinkage. When fillings were inspected after a period of water absorption, it was possible to determine the change in the width of the gap in relation to the length of period spent in water.

2. *Materials.* The brands listed in Table I were used in the investigation. Brands A to H contain inorganic filler (composite plastic filling materials) while brand I to K contain no inorganic filler (non-composite plastic filling

Table I.

List of brands used in the investigation

No.	Name	Batch no.	Manufacturer
A	Adaptic®	9Fo63	Johnson & Johnson, New Jersey, U.S.A.
B	Addent XV®	o166—02	3M Company, Minnesota, U.S.A.
C	Blendànt®	0702T616	Kerr Manufacturing Company, Michigan, U.S.A.
D	Concise®	0344 01C	3M Company Minnesota, U.S.A.
E	DFR®	Powder: 34202 Liquid: 62271	Surgident, Ltd., California, U.S.A.
F	Palakav®	—	Kulzer & Co., Homburg v.d.H., Germany
G	capsulated Palakav®	23970	Kulzer & Co., Homburg v.d.H., Germany
H	TD 71®	Powder: 016JC Liquid: 017IC Activator: 009FC	Dental Fillings, Ltd., London, England.
I	Palavit 55®	Powder: 6574 Liquid: 1092	Kulzer & Co., Homburg v.d.H., Germany
J	Sevriton Simplified®	Powder: LB3 Liquid: LL1 Adhesiv: LC9	De Trey Frères, S.A., Zurich, Switzerland.
K	Swedon®	Powder: 919 Liquid: 007 Reactor: 901	Svedia Dental Industri, Enköping, Sweden.

materials). The materials were used in accordance with the instructions of the respective manufacturers.

3. The teeth, preparations and the filling technic. Extracted teeth obtained from the surgical institute of the Royal Dental College, Copenhagen, were placed — until preparation — in a weak (approx. 1 % by weight) aqueous solution of chloramine. All the teeth were prepared at room temperature while in a wet state and at no stage prior to filling were they exposed to dehydration. A round diamond bur (diameter 2.3 mm) was used to penetrate the enamel, and the final cutting of the cavities was performed by means of a noncrosscut, straight fissure bur (diameter 1.4 mm) made of tungsten carbide. The cavities were prepared on non-carious periferal surfaces of crowns of all types of permanent teeth. The cavities were cylindrical in shape with a diameter and depth of approx. 2.5 mm. In all cases the bottom of the cavity was beneath the enamel-dentin junction, permitting observation of the adaptation to the dentin walls. The prepared teeth were stored in demineralized water in a thermostat room for at least 16 hours and at most 32 hours before the filling of the cavities. The thermostat room was maintained at 37 $\pm$ ½°C. The cavities were filled in clinically dry state, i.e. immediately prior to filling they were dried by compressed air, the temperature of which was close to room temperature. The filling materials were mixed at room temperature and were then carried into the thermostat room, where the cavities were filled in less than 45 seconds. A matrix of the brand De Trey's Universal Contouring Strips was used to prevent evaporation of monomer from the surface of the fillings. After the initial setting the fillings were either inspected under the microscope or placed in water at 37°C for subsequent examination. The microscopic investigation was conducted in the thermostat room.

4. Polishing technic and timing. In order to be able to assess the degree of adaptation of the plastic material to the cavity walls it was necessary to grind off the flash that covered the cavity margins. This was done under water at 37°C on carborundum paper no. 600. The teeth were gently abraded on a hard flat underlay approximately parallel to the surface or the fillings until all the flash was removed and a narrow ring of enamel could be seen all the way round the cavities. The subsequent polishing was then carried out on polishing linen with an aqueous suspension of fine corundum powder with a particle size designation of 0.3 microns. The process of abrading and polishing a filling took approx. 10 minutes, during which time the filling material had an opportunity to absorb water. The temperature of the water in which the teeth were abraded decreased 2—3°C during the abrading time because of evaporation of water.

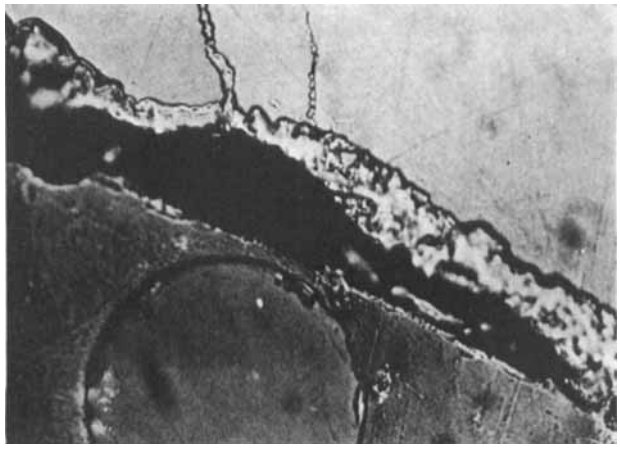

Fig. 1. Defective enamel margin, Class 1. × 425.

In cases where adaptation to the cavity walls was poor, the polishing powder was pressed into the gaps and hindered accurate measurements. It proved possible however to remove this powder to a sufficient extent by rinsing the filling under a jet of water from a squeeze bottle. Before the microscopic examination water droplets on the polished surface were removed with compressed air and by wiping with lens tissue.

Abrading and polishing were executed either 10 minutes after the filling of the cavities or after a varying number of days storage of the filled teeth in water at 37°C. Duration of time spent in water was except for Sevriton Simplified 24 ± 1, 48 ± 2, 96 ± 4, 192 ± 8, 384 ± 8 or 768 ± 8 hours. For Sevriton Simplified the times were $6\pm1/4$, $12\pm1/2$ or 24 ± 1 hours.

5. Classification of the damaged enamel margins. Investigation of the polished fillings revealed that in many cases the enamel margins were badly damaged. The damaged margins made it impossible to carry out a reliable measurement of the gaps because enamel fragments were pressed into the space between the filling materials and the tooth. Instead therefore the quality of the enamel margins was classified according to the following criteria:

Class 1: Extensive, complicated fractures over large areas of the enamel margin with displacement of the fragments. Width of the fracture zone often more than 15 microns. Large and small fragments of enamel broken off (Fig. 1).

Class 2: Sporadic fractures with or without slight displacement of fragments.

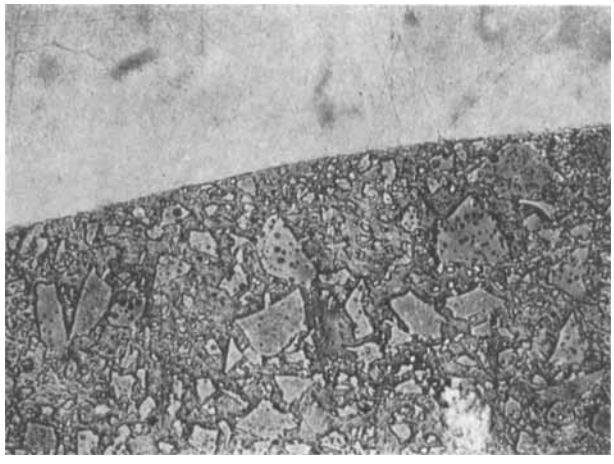

Fig. 2. Undamaged enamel margin, Class 3. × 425.

Width of fracture zone not more than 15 microns. Enamel broken off only in isolated places.

Class 3: No continuous fractures or broken enamel. In a few cases small, discontinuous fractures (Fig. 2).

6. Measuring the width of gaps in the dentin region. After the microscopic study of the adaptation to the enamel and the appearance of the enamel margins, the fillings were abraded down to the dentin and polished as before. This treatment did not produce marginal fractures (Fig. 3), and it was thus possible to measure the width of gaps in this region. The gaps were measured approx. 45 minutes after start of mixing of the filling material or — in the case of fillings which had been stored in water — about 30 minutes after start of abrasion in the enamel region. Measurements were taken at diametrically opposing points on the approximately circular section of the filling, and the total gap was found by addition. The corresponding diameter of the cavity was also measured. Measurement of the total gap was recorded at points where the gap was greatest. It was then possible on this basis to compute the percentage gap width existing at the time of observation. To eliminate the risk of any change of the gaps due to dehydration of filling material and teeth, the gaps were measured immediately after the polished fillings had been blown dry. During the time it took to carry out the measurements no alteration in the width of the gaps was observed.

7. Microscopic technique. In order to gauge the gaps the authors employed a Reichert MeF Universal Camera Microscope with measuring ocular. The

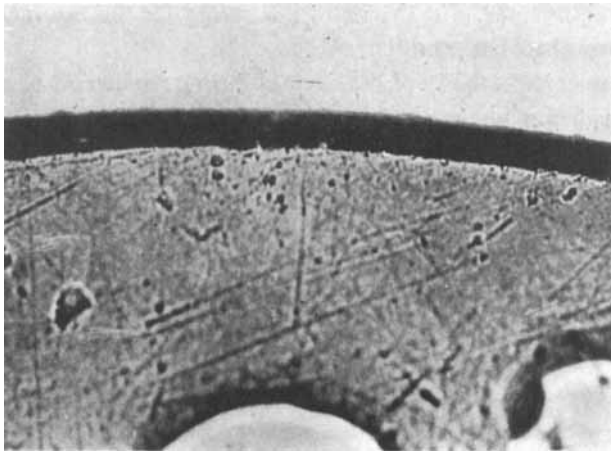

Fig. 3. Shrinkage gap in the dentin region of a cavity. × 425.

study material was examined in reflected light. Dry objectives were used, providing a nominal enlargement of 63 times; the measuring ocular enlarged 8 times. Gaps as narrow as 0.5 microns could be observed. Diameters of the cavities were measured using an ocular measuring scale with nominal enlargement 8 times and an objective with nominal enlargement 8 times.

Control of the method

1. In order to discover whether the selected classification of marginal enamel defects was capable of being reproduced, both authors — after a period that eliminated memory as a factor — reclassified enamel margins which had previously been investigated (10 of each class). Identical classification was recorded with all margins in Class 3, whereas in certain cases there was some uncertainty about classification of margins in Class 2 and Class 1; the uncertainty was present both in the minds of the individual observers and between the two observers. In the final classification, in which all the experimental material was classified by one of the authors alone (E.A.), the uncertainty was expressed by the fact, for example, that a margin might be described as 'Class 2 but almost as bad as Class 1', or 'Class 2 but almost as good as Class 3'. (Compare, for example, diagrams in Figs. 4, 6 and 9).
2. Accuracy of measurement of the gap in the dentin region of the cavity. The maximum width of gap for a given filling was measured a total of 10 times, the preparation being removed and relocated under the microscope

between measurements. The degree of inaccuracy for the repeated measurements was less than 1 micron.

3. The dimensional stability of the cavities during the period of observation (max. 32 days) was investigated in the following manner: Three teeth were abraded and prepared as described under pts. 4 and 3; graphite marks, capable of certain identification under the measuring microscope, were placed on diametrically opposing regions of the cavity margins. Before the fiducial measurement the teeth were stored for 24 hours in demineralized water at 37°C. The distance between the points was measured, and the teeth were then replaced in water at 37°C. The microscopic measurements were carried out in the thermostat room, and they were repeated every seven days for 35 days. It was discovered that the dimensions of the cavities during this period were constant within the measuring tolerance of ± 1 micron of the microscope. Similar experiments, conducted at room temperature gave the same result.

4. The possible effect of the extracted teeth's storage in a chloramine solution on the adaptation of the filling material to the cavity walls was examined by measuring the gaps around fillings in freshly extracted teeth which had not been in contact with chloramine. No systematic difference could be shown between the width of the shrinkage gap of fillings in freshly extracted teeth and the corresponding gap in teeth preserved in chloramine. On the other hand, fillings in teeth which had been preserved for shorter or longer periods in the quaternary ammonium base, Rodalon, often had considerably greater shrinkage gaps than in the two cases mentioned above.

RESULTS

The results of the investigation are seen in the diagrams Figs. 4—14, the upper and lower parts, respectively, showing how the quality of the enamel margins and the gap-widths in the dentin region changed according to the length of time spent by the filling under water prior to abrading. When the fillings were abraded and polished and inspected immediately after initial setting, the enamel margins were found to be badly fractured in all cases. The fracture zone was 20—40 microns wide, with frequent loss of enamel fragments. If polishing were postponed until the fillings had been kept for some time in water, the quality of the enamel margins was found to have improved. During the period of 32 days during which observations were made, perfect enamel margins were obtained with Sevriton Simplified after 12 hours, Swedon after 4 days and Adaptic, Blendant and Palavit after

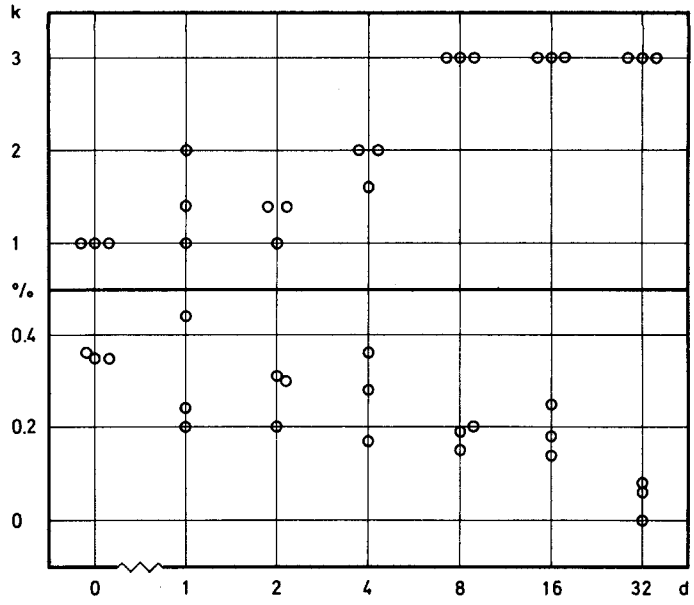

Fig. 4. Adaptic. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

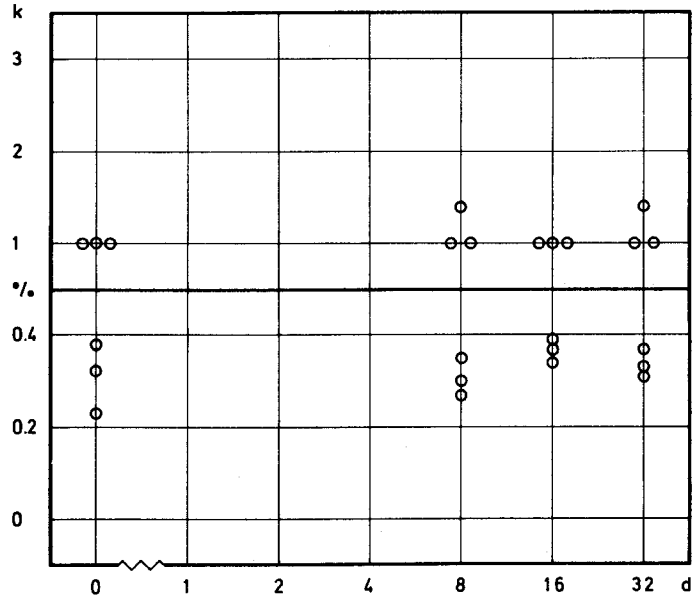

Fig. 5. Addent XV. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

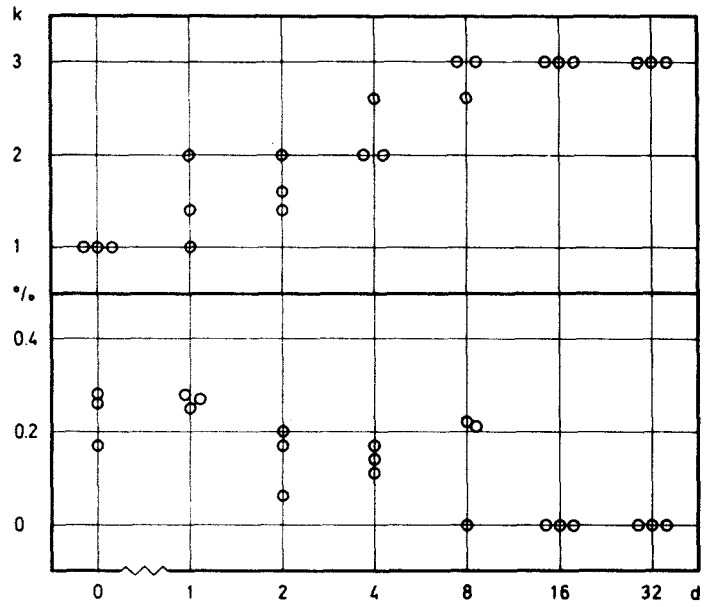

Fig. 6. Blendànt. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

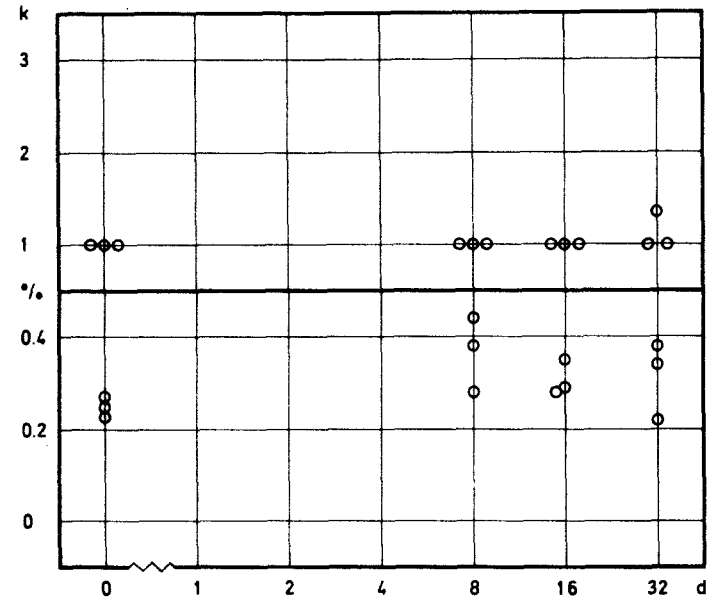

Fig. 7. Concise. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

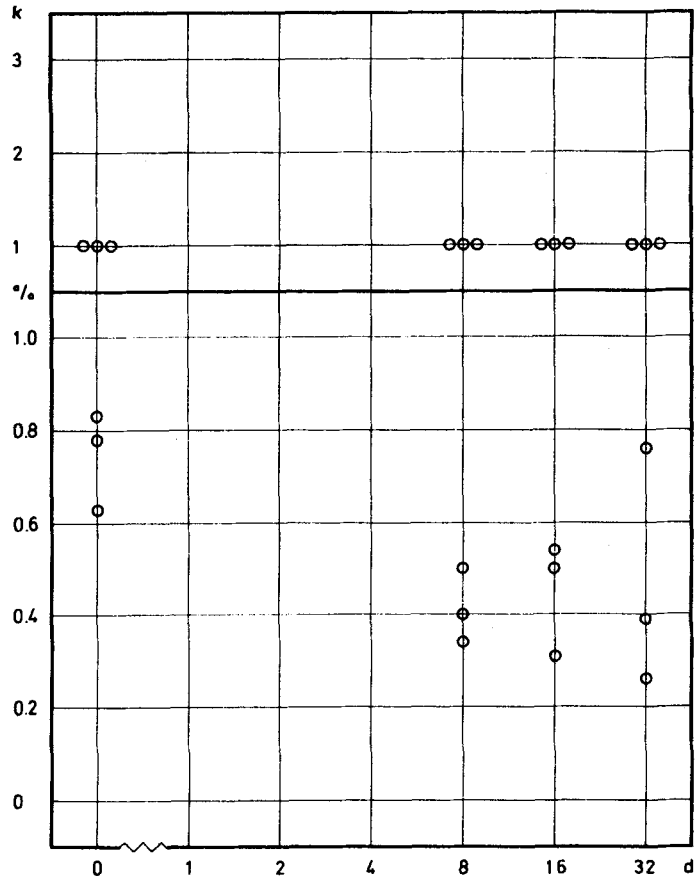

Fig. 8. D.F.R. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

8 days. In the dentin region, immediately after initial set, a gap was measured as an expression of the effective polymerization shrinkage. If the fillings had been immersed in water before examination, it was found that the gaps were smaller. In the case of Sevriton Simplified the gaps had closed after 12 hours, in the case of Palakav and capsulated Palakav the gaps closed after 2 days and in the case of Blendànt the gaps closed after 16 days. With the other brands the gaps had not closed after 32 days. Broadly speaking, there was a good correlation between the quality of the enamel margins and the width of the shrinkage gaps in the dentin region of the cavities.

The observed gaps were usually located along part of the filling margin while adaptation was perfect along the remainder of the margin.

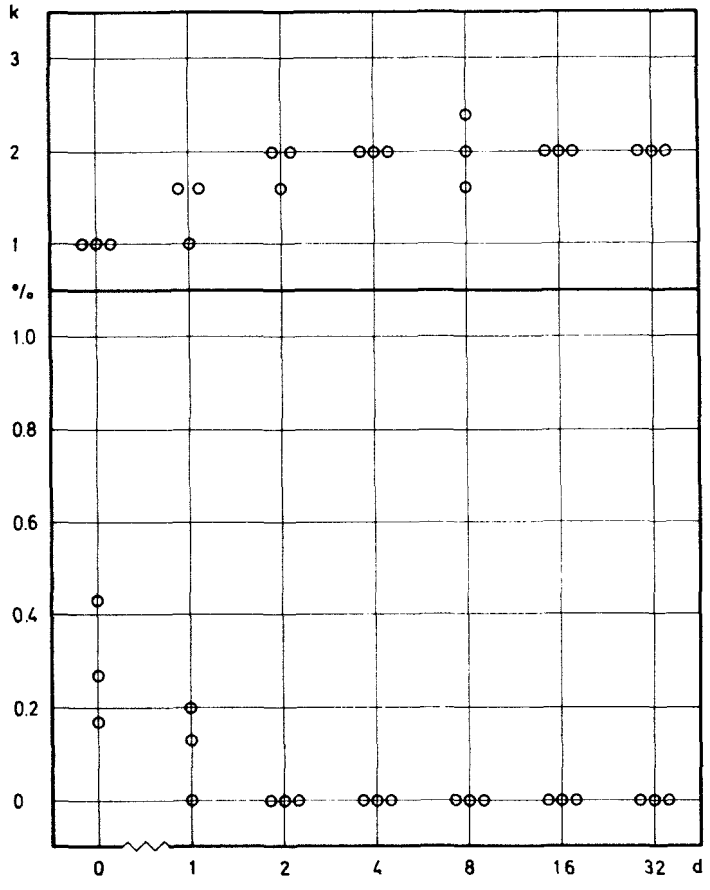

Fig. 9. Palakav. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

DISCUSSION

The foregoing has demonstrated the extent to which plastic filling materials change dimensions when applied in simulated clinical conditions. Earlier investigations have shown that measurements on free specimens reveal a polymerization shrinkage of 6—9 percent by volume for non-composite plastic materials (*Smith & Schoonover*, 1953) and 1.5—2.1 percent by volume for composite plastic materials (*Lee et al.*, 1969). From these figures the linear shrinkage can be calculated as one-third of the percentage by volume, i.e. 2—3 % for non-composite plastic materials and 0.5—0.7 % for composite plastic materials.

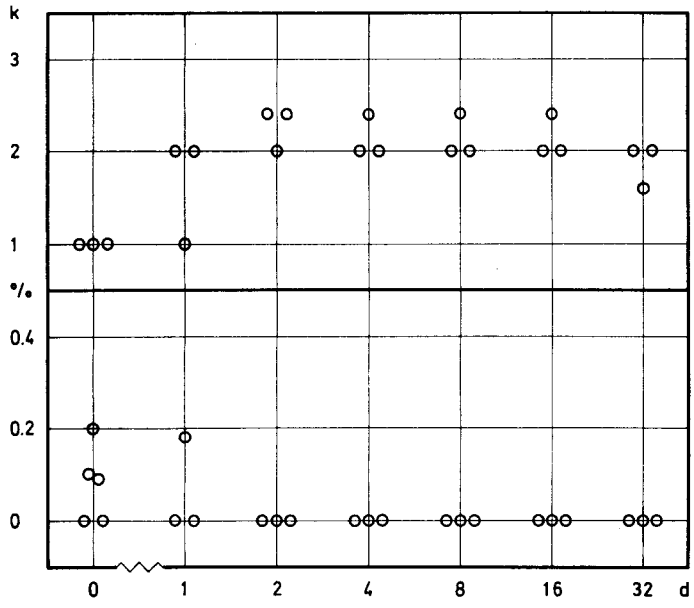

Fig. 10. Capsulated Palakav. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

The present investigation found no systematic difference between composite and non-composite plastic materials' effective shrinkage. This is no doubt due to the fact — indicated previously — that a plastic material which polymerizes in a cavity does not contract equally in every direction. During the initial stages of setting the plastic adheres to the cavity walls, and as long as this bond is maintained forces are in action which prevent wall-to-wall contraction, and shrinkage occurs exclusively from the free surface of the filling. It is not until the stresses in the material exceed the adhesion that the plastic will loose its grip on the cavity wall, whereby a gap is produced. The magnitude of the effective shrinkage will thus be conditional upon the balance between the forces of adhesion and the forces of contraction. Once a gap occurs somewhere along the margin of the filling, contraction can continue relatively unrestricted. The result is a filling which adapts perfectly along part of the margin but shows a crescent-shaped gap along another part of the margin.

It could be conceived that the fractured enamel margin occurs as a result of (1) the cavity preparation, (2) contraction stresses in the filling material

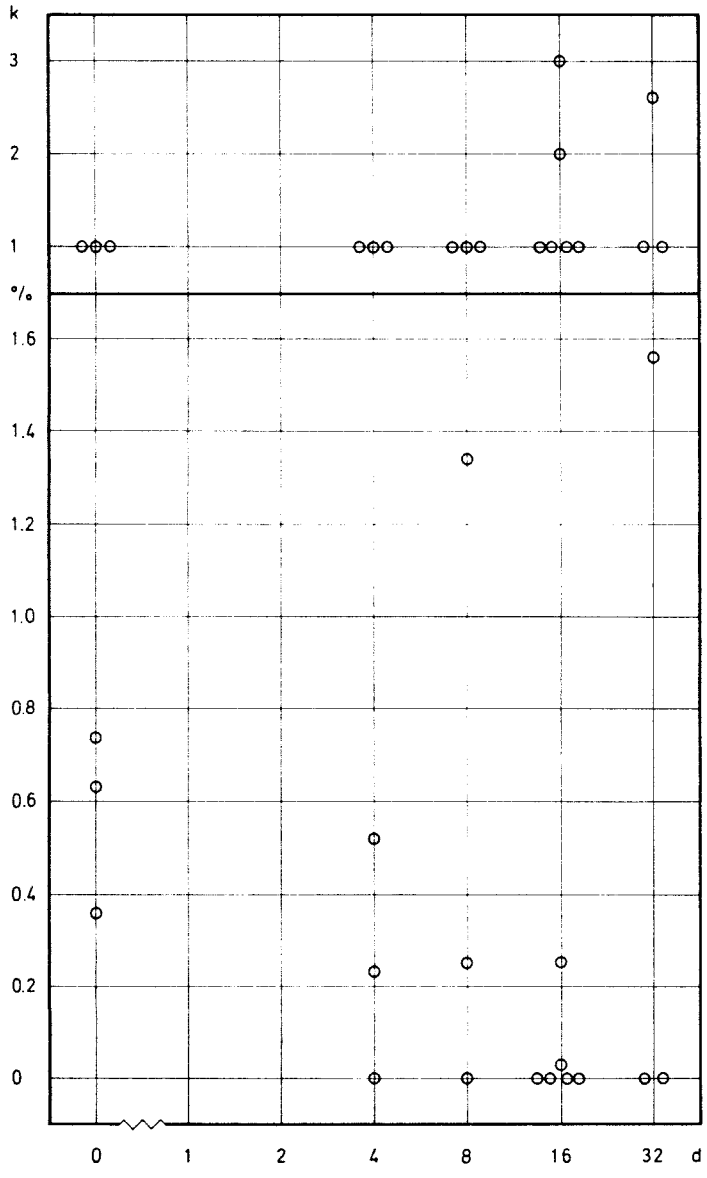

Fig. 11. TD 71. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

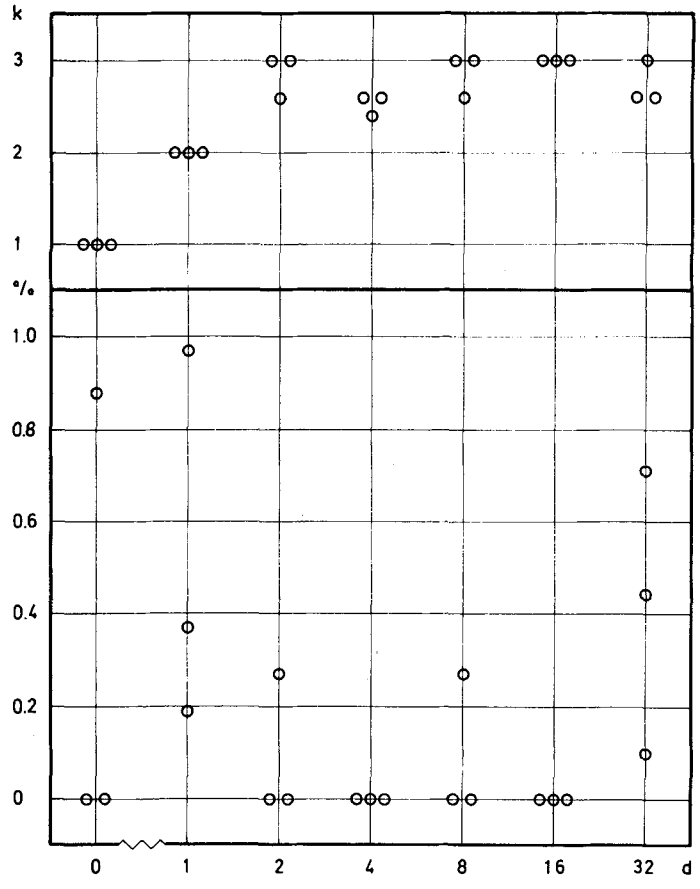

Fig. 12. Palavit 55. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

before initial adhesion between the material and the enamel wall comes to an end, or (3) abrading and polishing.

The following observations illuminate these possibilities.

A. Microscopic examinations of enamel margins around unfilled cavities cut in tooth surfaces which had already been ground flat never revealed marginal damage in form of Class 1 or 2 fractures.

B. When the fillings were abraded after the shrinkage gap had closed, the enamel margins were invariably of the Class 3 type.

C. In some cases defects in the form of air bubbles were observed in the marginal area of the filling. When such fillings were abraded after the shrink-

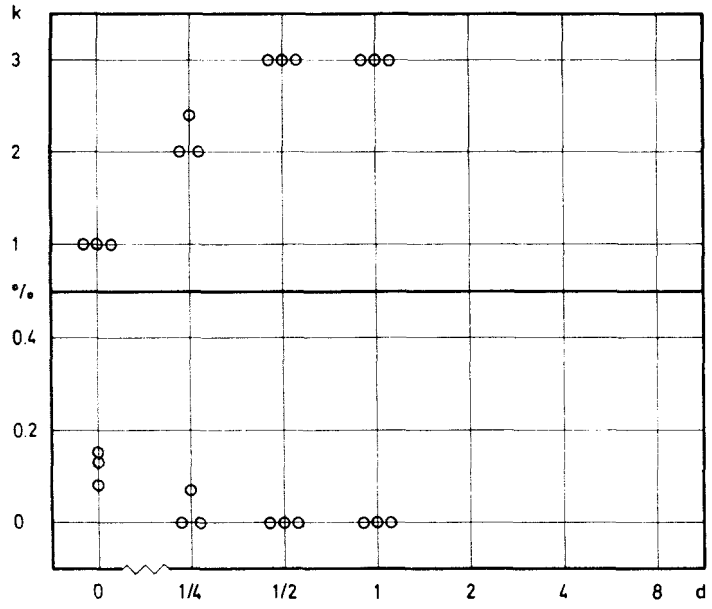

Fig. 13. Sevriton Simplified. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

age gap had closed as a result of water-absorption expansion, the enamel margins were found to break down only in regions corresponding to the marginal defects (Fig. 15).

Observations A and B exclude cavity preparations as a cause of defects of the enamel margin, whereas observations B and C exclude contraction stresses. The only possible explanation for the Class 1 and 2 marginal defects observed would thus seem to be the abrading process.

Figs. 4—14 show that polymerization shrinkage — after initial set — produces a gap in all the plastic filling materials investigated. As a result, the enamel margins are unsupported, and abrading will apply tension to the enamel — causing the margin to fracture. The tensile strength of the plastic materials is so great that the filling margins are not destroyed by the abrading process. If the filling is immersed in water before abrading, water-absorption expansion will compensate wholly or partly for contraction, and this will improve the adaptation. Complete compensation causes the plastic material to support the enamel, and this permits the fillings to be abraded without fractures occurring in the enamel margins. This can be seen with Adaptic, Blendànt, Palavit 55, Sevriton Simplified and Swedon (Figs. 4, 6, 12, 13, 14).

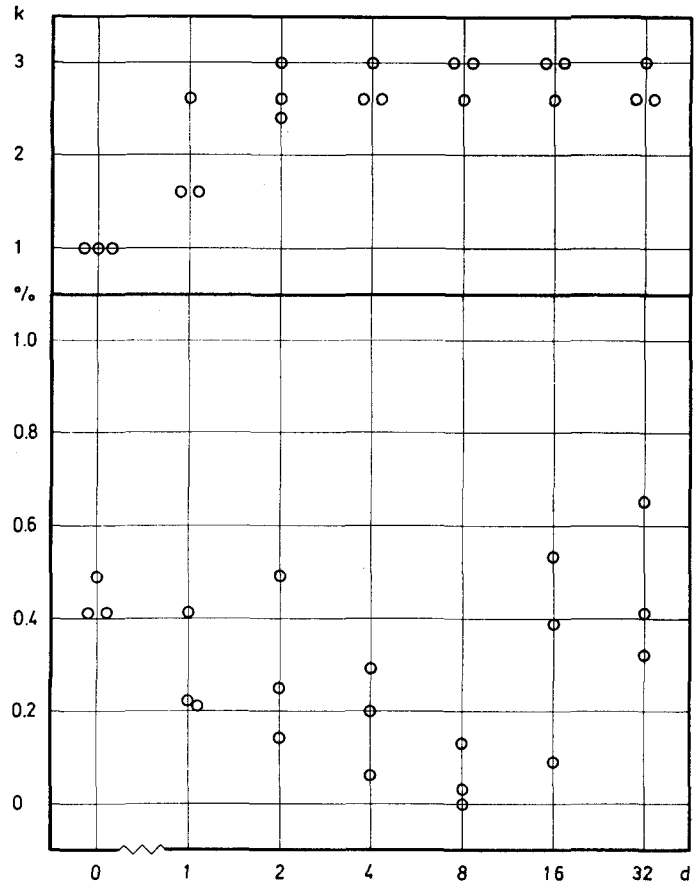

Fig. 14. Swedon. Influence of the immersion time in water on the quality of the enamel margin (upper part of the diagram) and upon the percentage gap width in the dentin region (lower part of the diagram). The fillings were polished at the time specified on the abscissa.

The great variations in gap widths measured in TD 71 (Fig. 11) may be explained with reference to the very short setting time of this material. When it is placed into the cavity, it is already so dry that it frequently adheres poorly to the cavity walls. The forces of contraction are either not resisted by adhesion at all or only to a very small degree.

The relatively wide shrinkage gaps in Palavit 55 (Fig. 12) are due to adaptation features peculiar to this material which will be discussed in a later article. With Palakav and capsulated Palakav no gaps could be observed in the enamel region, if the abrading and polishing were postponed 2 days or more. The fact that the quality of the enamel margins does not become

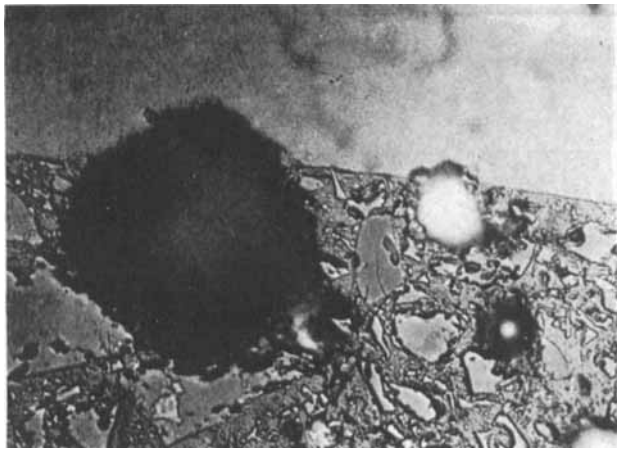

Fig. 15. Fractured enamel margin resulting from abrasion of a filling after closure of the shrinkage gap by water-absorption. A marginal air bubble has caused a local lack of support of the enamel margin. The margin is fractured only in the area where the air bubble was in contact with the cavity margin. × 425.

perfect even when the fillings were not finished until after 32 days in water, is due to frequent loss of filler particles. When a filler particle is lost in the abrading process a void in the plastic is produced. Voids too close to the filling margins lead to the observed enamel fractures because of insufficient support of the enamel.

The present work may be compared with the investigation of *Asmussen & Jørgensen* (1971) where a similar series of measurements was carried out at room temperature. It is seen that initial gap size, given the brand, does not vary greatly with temperature. What does vary is the time of closure of the shrinkage gaps. This is most clearly demonstrated in the cases of Adaptic and Blendant. The earlier closure of the gaps at oral temperature than at room temperature is explained by the greater rate of diffusion of water at the higher temperature.

It may be concluded that fractures of the enamel margin as a result of abrading can be reduced to a minimum, if this step is postponed until after the shrinkage gap has closed as a consequence of water-absorption and that the risk of secondary damage is thus reduced.

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