From:
The Department of Technology,
Royal Dental College,
Copenhagen, Denmark

THE CRAZING OF SILICATE CEMENTS

by

KNUD DREYER JØRGENSEN
MASAAKI IWAKU

INTRODUCTION

It has been recognized for many years that silicate cement can craze when subjected to drying. It was not however until recently, i.e. the marketing of the undernoted brand no. 7, that crazing was actually made the subject of investigation (*Baumann & Beham*, 1968; *Eichner*, 1968). The former two authors demonstrated that in laboratory tests silicate cement crazes for only a relatively brief period after the cement has been mixed; the latter author was of the opinion that crazing occurs only in special laboratory conditions, and does not occur when the cement is used in the clinic for making dental fillings.

The purpose of the present work has been (A) to study the crazing of silicate cement in controlled laboratory experiments, (B) to study by means of laboratory experiments the practical clinical consequences of crazing, and (C) to test whether from the point of view of crazing the cement in clinical application reacts in the same manner as in laboratory experiments.

MATERIALS AND GENERAL METHOD

The brands named in Table I were used in the study. The cements were mixed normally to the standard consistency described in F.D.I. specifi-

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cation no. 5, except for the fact that in all cases the quantity of acid was only 0.057 ml; in one particular series of experiments (see later) thicker and thinner mixtures were tested than those corresponding to the standard consistency of the specification.

In all cases the cement was mixed at room temperature, which was 23±1°C, and at a relative humidity of 40±5 %.

Table I

List of brands studied

No.	Brand	Batch no.	Manufacturer
1	Astralit improved	—	Dental Fillings Ltd., U.K.
2	Super Syntrex	P:GAI.L:FJ1	De Trey Frères S. A., Switzerland
3	Silicap	P:057.L:661D	Vivadent, Liechtenstein
4	New Filling Porcelain	P:056634.L:126634	S.S. White Dental Mfg.Co., U.K.
5	B.S. 58	P:4Z1.L: —	Bayer, Leverkusen, W. Germany
6	Super Diafil	P:F3436.L:C3076	Pfingst & Company Inc., U.S.A.
7	Biotrey	P:HL7.L:HH1	Amalgamated Dent. Co., U.K.
8	Achatite Biochromatic	P:485.L:501	Vivadent, Liechtenstein

Crazing of the cement was demonstrated with the aid of a felt-tip marker, which was drawn lightly across the surface of the cement. The properties of the marker fluid must be such that it flows readily and moistens the cement easily; it must also dry within a few seconds. In the study a felt-tip marker manufactured by Linz, a West German company, was used; it meets the above-mentioned requirements. The marker fluid will penetrate any cracks which occur as a result of crazing and will indicate their presence clearly in the form of sharply drawn, black lines. It was proved by inspection through a stereoscopic microscope that the felt-tip marker neither caused nor altered the crazing of the cement.

Details of the methodology applied are given in each of the following sub-sections relating to the results of the study.

A. LABORATORY EXPERIMENTS ON THE CRAZING OF CEMENT

(a) *The effect of time on crazing*

Method. Immediately after mixing, the cement was transferred to a flat, cylindrical brass mold (diameter 10.0 mm, depth 1.0 mm), which had been placed on a 20 μ thick sheet of tin foil on a flat glass slab. A second glass slab covered with tin foil was then pressed downward against the surface of the cement at a pressure of approx. 2 kg. Filling and sealing of the mold lasted approx. 20 seconds, and the pressure on the surface of the mold was maintained for a period of about the same length. Two minutes after mixing had commenced the mold, complete with tin foil but without the glass slabs, was transferred to a thermostat with a temperature of 37.0°C where it was placed on the flat surface of a heavy brass block in order to attain the temperature of the thermostat as rapidly as possible. Relative humidity in the thermostat was 20 %.

After periods of various durations the molds were removed from the thermostat and the tin foil from the surface of the cement. Immediately thereafter (i.e. no later than two seconds after the removal of the tin foil) the cement was tested for crazing. If crazing was not evident at this early stage, a new test was made every 10 seconds for the first four minutes, subsequently at greater intervals until crazing was shown to have occurred or until a period of at least 3000 minutes had elapsed.

A number of check tests revealed in all cases that the possibility of reproducing the time of commencement of the crazing was better than ±10 %. In the final experiments the time of commencement of crazing was determined only once for each combination of variables. Brands 1, 2, 6 and 7 were used in the study.

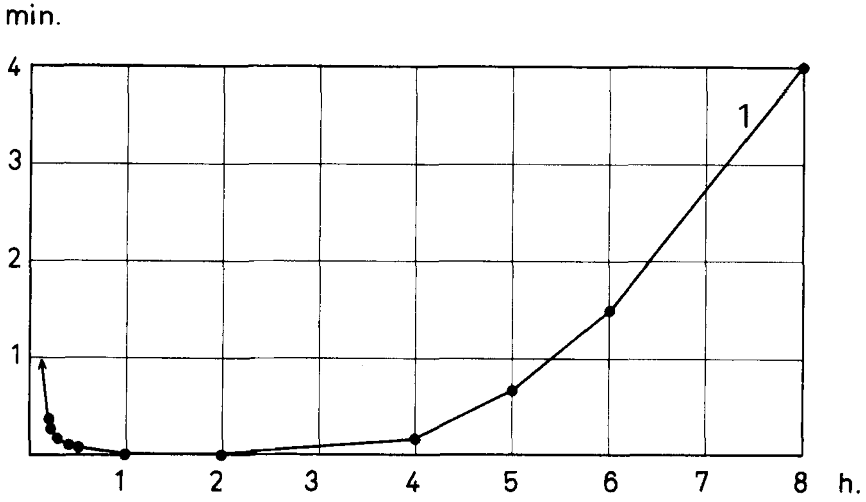

Fig. 1. The time at which crazing started (ordinate in minutes), depending on the age of the test specimens (abscissa in hours) calculated from the commencement of the mixing process. Brand no. 1.

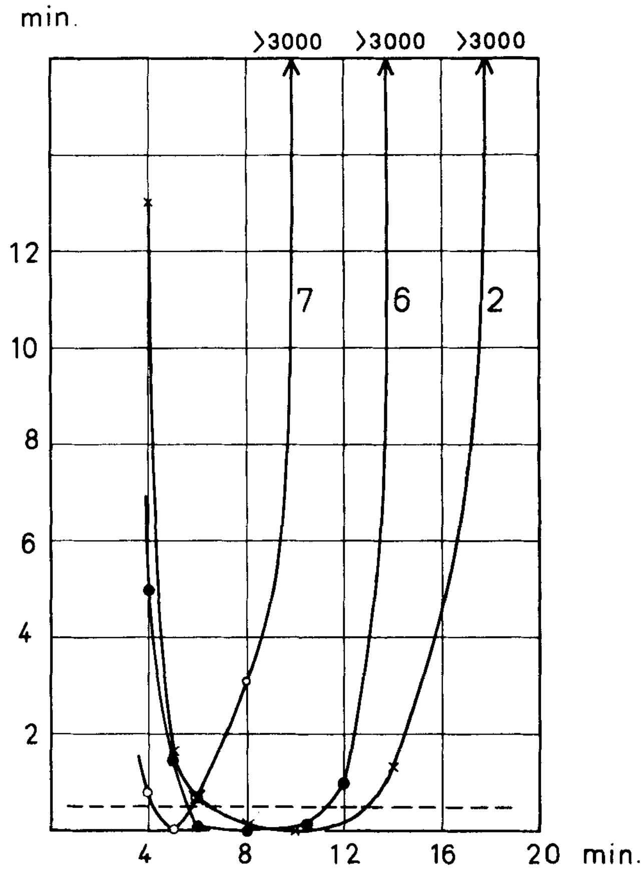

Fig. 2. The time at which crazing started (ordinate in minutes), depending on the age of the test specimens (abscissa in minutes) calculated from the commencement of the mixing process. Brand nos. 2, 6 and 7.

Results. The results are shown in diagrams in Figs. 1 and 2. The curves in the two diagrams can be described as *crazing curves*, and they show at what time initial crazing occurred in test specimens of different ages.

If, after the removal of the tin foil and before the anticipated commencement of crazing, the test specimens were given a protective film of, for example, vaseline or varnish, they will not at any later stage show signs of crazing. In clinical practice a protective agent of this type can without difficulty be applied to a silicate cement filling within 30 seconds of the removal of the matrix. The time interval (calculated from the start of the mixing process) within which the silicate cement crazes no later than 30 seconds after the removal of the matrix can be termed the *crazing period.* The 30-second level is indicated in Fig. 2 by a broken line. The interval between the intersections formed by this line with a brand's crazing curves indicate the crazing period for that particular cement. During approximately the last third of this period the intensity of crazing decreases at an even rate.

The shape of the crazing curves indicates that when the cement reaches a certain age it can for all practical purposes be described as crazing-resistant, i.e. the cement does not craze within at least 48 hours of the removal of the matrix. The age necessary for attainment of crazing-resistance can — in the case of brands 2, 6 and 7 — be observed from the diagram in Fig. 2. Brand no. 1 displayed crazing-resistance after 24 hours.

(b) *The effect of brand and temperature on the crazing period*

Method. The test specimens were made in the same manner as described in (a), although a group of these were allowed to set in a thermostat at a temperature of 30.0°C and with a relative humidity of 32 %. The specimens were removed from the thermostat at different intervals after the commencement of mixing, and recording of crazing occurred in all cases 30 seconds after removal from the thermostat. Every single brand was tested for crazing on test specimens with a maximum difference in age of one minute. The accuracy of the method and the number of specimens was as described in (a). The setting time of the cement at the given thermostat temperature and relative humidity was measured by means of the Gillmore I method (Gillmore initial set, A.S.T.M. standard C 191—44); during this measurement the top surface of the test specimens was not protected by tin foil; the accuracy of the measurement was to within ±15 seconds. All eight brands were used in this study but the crazing period at 30° was not determined in the case of brands 1 and 5.

Results. The results of the test are shown in diagram form in Fig. 3. The crazing period at 37° is indicated by means of unbroken lines, while the crazing period at 30° is indicated by broken lines. In the case of each individual brand the times at which the crazing period commenced or concluded at 37° and 30° are linked by a thin line. The Gillmore I time is shown by means of open circles under the crazing period of each cement.

The results show that the duration of the respective crazing periods varies considerably from brand to brand. Brands 4 and 7 had very short crazing periods at both 37° and 30°, whereas brand no. 1 had an extremely long crazing period (Compare Fig. 1).

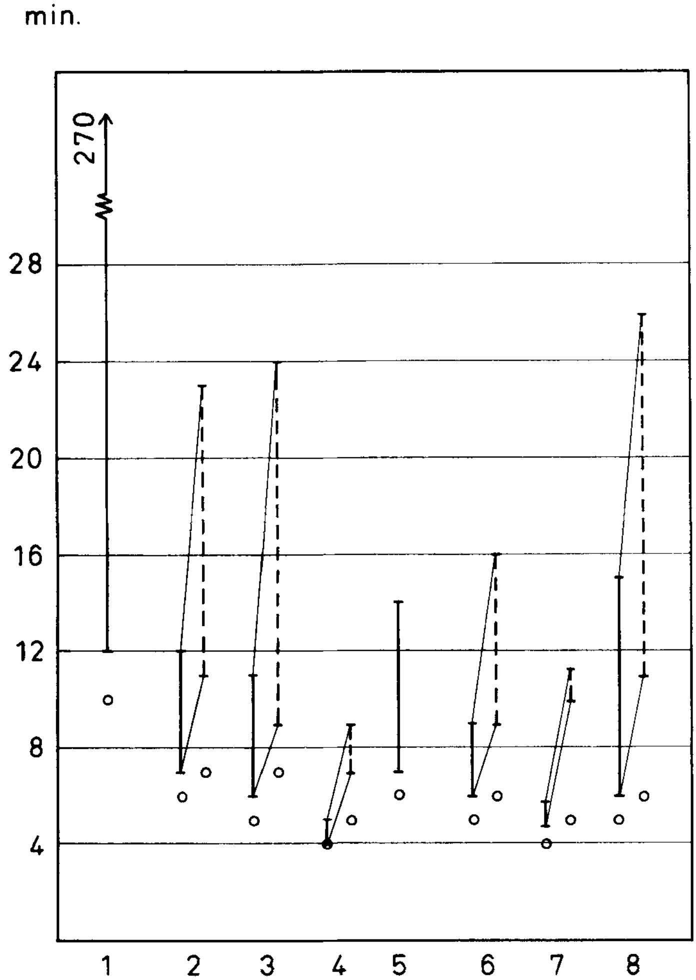

Fig. 3. The dependence of the crazing period on brand and temperature. Numbers 1 to 8 refer to the brands studied. Unbroken vertical line: the crazing period at 37°C. Broken vertical line: the crazing period at 30°C. Open circles: Gillmore I time for the various cements at either 37° or 30°.

When a silicate cement has set to a degree corresponding to the Gillmore I time, it no longer adheres to the matrix, and has lost a great deal of its plasticity. The Gillmore I time thus represents a setting degree of practical interest after which the matrix can be removed from a filling, and the filling can be coated with, for example, vaseline or varnish without any risk of its being deformed. The diagram in Fig. 3 shows that in almost every instance the Gillmore I time occurs before the time crazing commences. The diagram also shows that the crazing period is delayed and extended when the temperature is lowered.

(c) *The effect of the powder/acid mixture proportions on the crazing period*

Method. Only brand nos. 2 and 7 were used in this test. The cements were mixed in different proportions between powder and acid, as indicated in the caption under diagram Fig. 4. It may be noted that the absolute quantity of acid applied in each case was constant, viz. 0.057 ml. The methodology was otherwise as described earlier in (b).

Results. The results are shown in diagram form in Fig. 4, which reveals that the crazing period commences at an earlier stage, the thicker the cement is mixed.

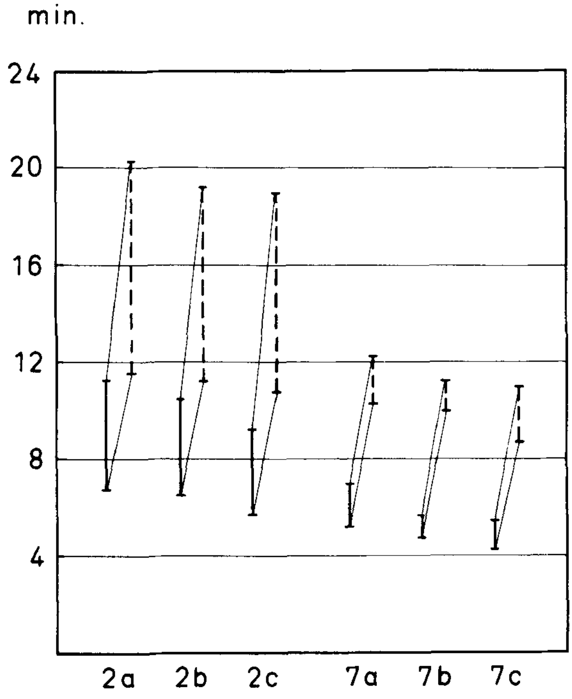

Fig. 4. Crazing period for brands 2 and 7 at 37° and 30°C, depending on the mixture proportions g powdeı/ml acid.
2a: 1.45/0.40. 2b: 1.50/0.40 (normal consistency). 2c: 1.55/0.40.
7a: 1.25/0.40. 7b: 1.30/0.40 (normal consistency). 7c: 1.35/0.40.

(d) *The effect of the size of the test specimens on the crazing period*

Method. The dimensions of the molds used in the normal experiments were 10.0 × 1.0 mm; in addition to this format tests were conducted with molds measuring 3.0 × 2.0 mm and 3.0 × 1.0 mm. Crazing periods were determined only for brands 2 and 7 and only at 37°; the *technic* was otherwise as described in (b).

Results. The results are shown in the diagram in Fig. 5. It is observed that the dimensions of the test specimens have a considerable effect on both the commencement and duration of the crazing period. The reason for this phenomenon is not immediately apparent, and experiments were not conducted to illuminate the position.

(e) *The significance of the matrix material with regard to crazing*

Method. Foil of celluloid, cellulose acetate, polyethylene and cellophane was used to protect the silicate cement during setting at 37°. The technic was otherwise as described in (b).

Results. The first three matrix materials produced the same crazing period as the use of tin foil had done. On the other hand no crazing occurred within 30 seconds of the removal of the matrix when cellophane was used.

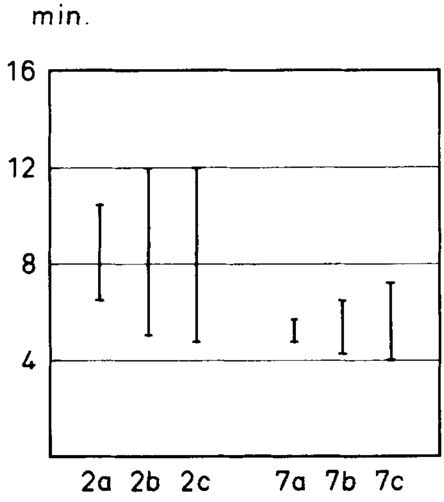

Fig. 5. The effect of the dimensions of test specimens on the crazing period at 37° for brands 2 and 7.
a: 10.0×1.0 mm. b: 3.0×2.0 mm. c: 3.0×1.0 mm.

The cellophane foil was not however able to eliminate completely the crazing tendencies of the respective cements; when the cellophane was removed from the test specimens at the stage where — if tin foil had been employed — these would have been subject to immediate and intensive crazing, the earliest and relatively mild forms of crazing occurred in the various brands after the following times: 1. later than 300 seconds; 2. 50 seconds; 3. 170 seconds; 4. 90 seconds; 5. 40 seconds; 6. 130 seconds; 7. 60 seconds; and 8. 40 seconds. It was thus shown that cellophane foil delays the crazing of silicate cement sufficiently to allow time after the removal of the foil and before the commencement of crazing to cover the cement with, for example, vaseline or varnish; once the cement has been covered by these protective agents no subsequent crazing can be shown to have occurred in its surface.

The curves in the diagrams at Figs. 1 and 2 indicate that crazing will occur relatively late if the matrix is removed from the surface of the cement very soon after the manufacture of the test specimens. From the point of view of experiment such an early removal of the matrix is not acceptable because of adhesion between matrix and cement, which would lead to deformation of the test specimens and — in clinical practice — of the fillings. On the other hand the test specimens can be left in the thermostat without a foil cover and with an exposed surface which has merely been smoothed with a spatula. Experiments of this nature, corresponding to the abscissa time of two minutes in Figs. 1 and 2, showed that the cements did not craze until they had reached at least a degree of setting equal to the Gillmore I time.

(f) *The significance of moisture with regard to crazing*

Method. Test specimens of brands 2, 3, 6 and 8 were made according to the method described in (a). At the stage of setting when by the normal method such specimens showed signs of early and intensive crazing they were transferred to a glove box at room temperature and with a relative humidity of either 65 %, 75 % or 85 %. The tin foil was then removed immediately, and the surface of the cement was during the period that followed examined for crazing.

Results. Crazing occurred a few seconds later at 65 % relative humidity than at the 40±5 % of the normal experiments. At a relative humidity of 75 % crazing had not occurred at 30 seconds, and at 85 % relative humidity no crazing was evident after five minutes.

(g) *The width and depth of the crazing cracks. General description of the crazed cement surfaces*

Method. Test specimens of brands 1, 3 and 4 were made in accordance with the method described in (a) and for 30 seconds were exposed to crazing at a stage when early and intensive crazing had been recorded. The specimens were then transferred to a container with a temperature of 37° and a relative humidity of 100 %, where they were stored for 24 hours. The width of the crazing cracks was measured after the test specimens had been allowed to lie for a further period of 24 hours in water at a temperature of 37°.

The depth of the crazing cracks was measured on test specimens of brands 1—8, which had been employed in the study described in (b). The dry specimens were cut through at right angles to the crazed surface, and the depth of crack was measured to be the depth to which the dried fluid from the felt-tip marker had penetrated the cement.

Results. The width of the crazing cracks varied from microscopically unmeasurable to a maximum of 2.5 μ (Fig. 6); in this respect there was no difference between the respective brands examined. The width of the cracks increased as the cement dried; after 24 hours at approx. 23°C and a relative humidity of 40 % the maximum crack width was just under 5 μ and did not increase after a further period of 24 hours drying. When the specimens were then stored in water for several days no significant reduction could be recorded in the width of the cracks in the dried test specimens.

The maximum depth of the cracks was also independent of brand; it varied in different cuts between approx. 150 and 200 μ.

The concentration of cracks in intensively crazed surfaces was also independent of brand; Fig. 7, which shows a section of brand no. 1 measuring approx. 0.35×0.5 mm, may be regarded as typical of all the brands.

It was a characteristic feature of the crazed cement surfaces, both during macroscopic inspection and on a slight enlargement, that they were considerably more opaque than corresponding non-crazed surfaces were. The opacity was apparently caused by a change in the structure of the cement in the areas between the crazing cracks. The difference in opacity between crazed and uncrazed test specimens became evident simultaneous with the commencement of crazing on the test specimens (which were usually only a few minutes old) and it persisted for at least 24 hours, if the specimens were stored at 100 % humidity and 37°C. When the test specimens were then placed in water for 24 hours, the opacity of the crazed specimens was reduced to such an extent that these specimens could not be distinguished from uncrazed specimens. Subjected once more to a moderate drying process, the crazed specimens again became more opaque than the uncrazed.

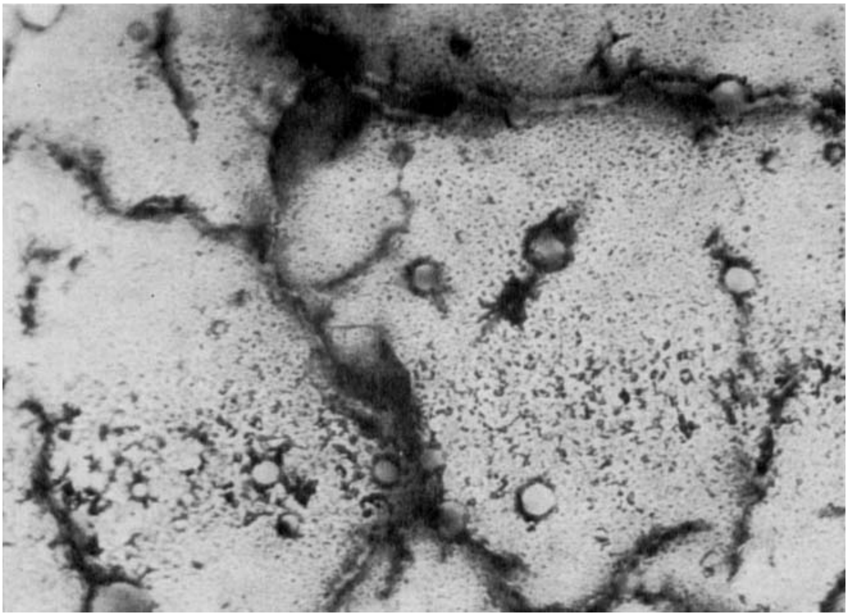

Fig. 6. Crazing cracks in brand no. 3. Maximum crack width is approx. 2.5 μ. × 800.

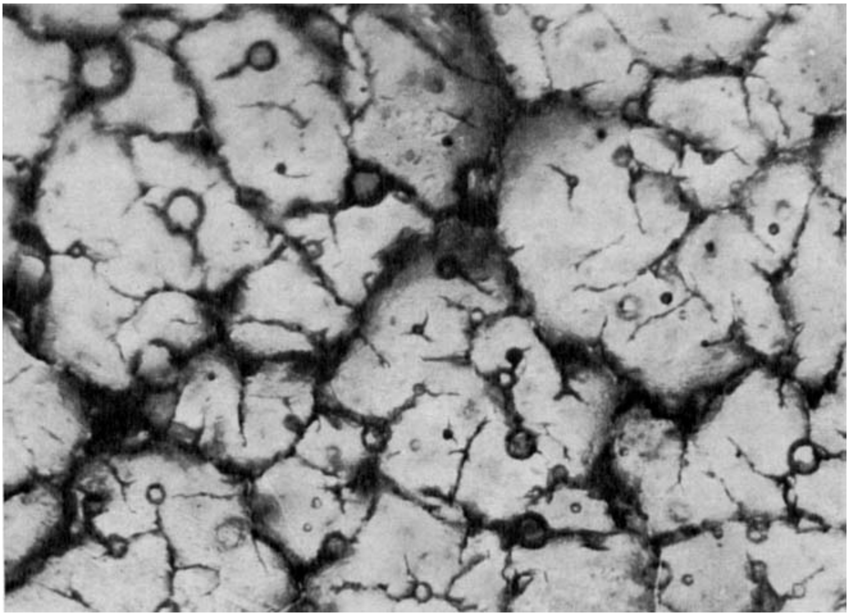

Fig. 7. The intensively crazed surface of brand no. 1. × 220.

B. LABORATORY EXPERIMENTS ON THE PRACTICAL CLINICAL CONSEQUENCES OF THE CRAZING OF CEMENT

(h) *Solubility in water*

Method. Brands 2 and 7 were employed in this study. The experiment was conducted in accordance with F.D.I. specification no. 5, except however that tin foil was used for separation between the cement and the glass slabs. In order to produce crazing on some of the test specimens the tin foil was removed from the surface of the cement at room temperature for one minute at a stage when the cements displayed early and intensive crazing. This measurement was carried out five times for each cement and with both crazed and uncrazed test specimens.

Results. Brand no. 2, uncrazed: 0.45±0.02 %, crazed: 0.49±0.03 %. Brand no. 7, uncrazed: 0.42±0.01 %, crazed: 0.45±0.02 %. The differences are almost significant for both groups but unlikely to be of any major importance in practice.

(i) *Solubility in* 0.001 *n lactic acid*

Method. Test specimens of brands 2 and 5 were made as described in (a). At the stage when the cements displayed early and intensive crazing the tin foil was removed from the surface of the cement. Two minutes later the test specimens were placed at a temperature of 37° in an atmosphere of 100 % humidity. When the specimens were 24 hours old, they were transferred to demineralized water with a temperature of 37° where they were stored for a further six days. The seven-day-old specimens were weighed and then placed for 24 hours in a 0.001 n solution of lactic acid; after the soft layer of crumbled cement had been brushed from the surface of the cement, the test specimens were weighed again and the loss of weight was calculated in per cent. Test specimens which had not been crazed were employed as a means of checking. The technic will not be discussed in detail at this stage, since it will be described in a special publication on the solubility of cements in acids. The publication is in the process of compilation. The number of test specimens in each of the study groups was five.

Results. The solubility of brand no. 2 was 7.8±1.4 % (check 3.1±0.8 %), and of brand no. 5 it was 4.7±0.8 % (check 2.6±0.8 %). The solubility of the crazed cements was thus about twice of corresponding uncrazed cements. Fig. 8 shows a section of approx. 1.2×1.7 mm of one of the crazed test specimens after the soft layer of crumbled cement had been brushed from the surface of the cement. The pattern of cracks is seen clearly, and

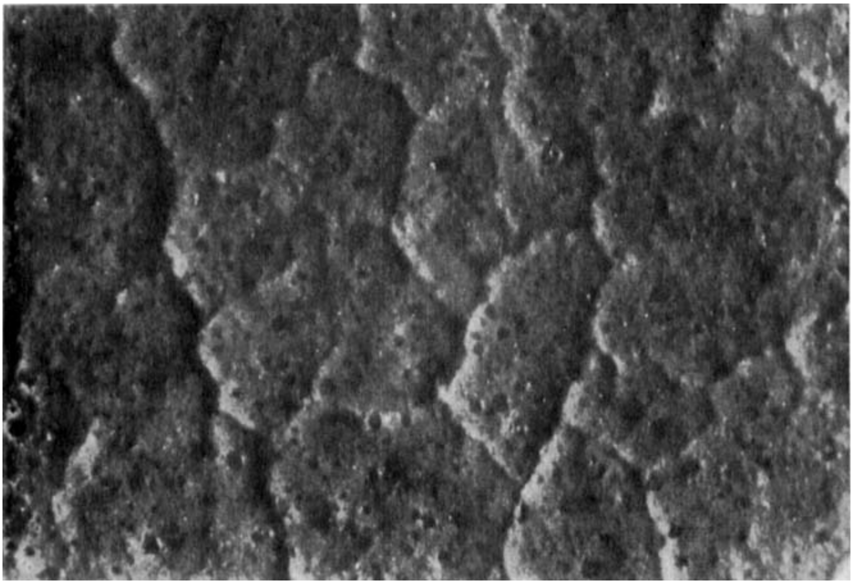

Fig. 8. Part of the surface of a test specimen (brand no. 2) after measurements had been carried out of the solubility in lactic acid of the crazed cement. × 90.

it can be observed how the edges of the cracks have been obviously rounded. This pattern could not be seen before the crumbled layer was brushed off.

It can be mentioned here that rather a similar, soft, chalky layer of crumbled cement is also frequently seen on dental fillings. When this layer is brushed off such fillings, a clear crazing pattern is occasionally revealed.

After acid solubility experiments with test specimens and with experimental fillings made in the laboratory in extracted teeth, brushing can not infrequently bring to light local marginal defects in the crazed cement (Fig. 9). In this instance the acid had apparently dislodged a fragment of the cement by corroding in the surrounding cracks.

(k) *Discoloration.*

Method. Eighteen test specimens of each of brands 1, 3 and 4 were made as described above in (g). Three crazed and three uncrazed of the 48-hour-old test specimens of each of the brands were placed for five minutes in soy sauce, while three plus three others — again of each brand — were placed for the same length of time in a 6 % solution of red azo-dye (»red fruit coloring»). At the end of this period the test specimens were removed from

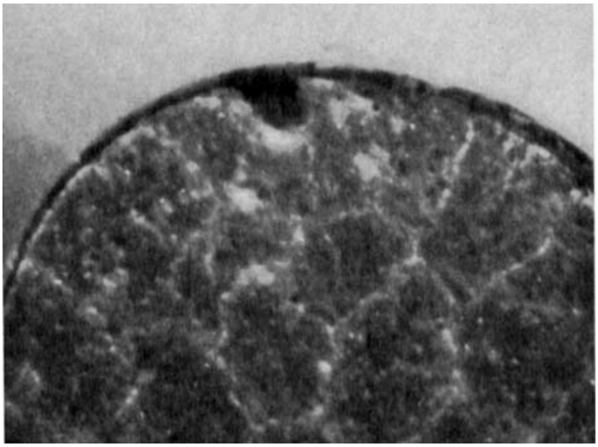

Fig. 9. Marginal area of experimental filling after the test for solubility in lactic acid. A fragment of the edge of the filling was removed while the filling surface was being brushed. × 30.

the coloring solutions, and excesses of coloring agent were rinsed off under running water. While still wet the colored test specimens were compared with the control specimens by a simple macroscopic inspection and by enlargement to about 10 times original size.

Results. The group of crazed test specimens that had been treated with the dye solutions was severely discolored. Discoloration was general and was not particularly localized around the cracks produced by crazing (compare with the remarks on opacity in (g)), the cracks merely appearing as slightly more intensively colored lines. After a prolonged period of rinsing, the red dye disappeared from the test specimens within a few minutes, whereas the brown dye could still be discerned slightly after about one hour. For the most part therefore discoloration was reversible. The group of uncrazed test specimens displayed no discoloration compared with the control specimens, which had not been treated in the dye solution.

(l) *Flexure strength*

Method. Ten test specimens of each of the eight brands were made as described in (g), five specimens of each brand being crazed and five being uncrazed. Forty-eight hours after manufacture the disk-shaped specimens were placed in a specially constructed apparatus for testing the flexure strength. In the apparatus the edge of each disk specimen was supported by a circular metal ring about 1 mm wide. Stress was applied to the center of the test specimens by means of a 5 mm steel ball at a load rate of approx. 100 g per second.

Results. The mean value and standard deviation of the measurements are given in Table II, which also shows the computed t-value from Student's t-test.

Table II
Flexure strength (grams) of uncrazed and crazed silicate cement
N = 5

Brand	Uncrazed		Crazed		t-value
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	
1	1268	46	1128	54	4.41
2	1484	79	1228	67	5.51
3	1584	124	1420	110	2.20
4	1744	84	1352	78	7.63
5	1576	74	1448	73	2.75
6	1616	74	1580	76	0.76
7	1580	79	1260	58	7.30
8	1252	54	1228	67	0.62

The measurements show that the mean value of the flexure strength of crazed cement is in all cases lower than that of uncrazed cement, and that the differences in several cases are particularly notable while in other cases the differenrences are very slight. Considering the rather great depth of the crazing cracks (up to approx. 0.2 mm on each side of the 1.0 mm thick test specimen), the effect of crazing on the flexure strength is however surprisingly small.

C. THE CRAZING OF SILICATE CEMENT IN CLINICAL CONDITIONS

The experiments described in the foregoing showed that the crazing of a silicate cement depends to a major extent on (1) the time that expires after mixing commences, (2) the temperature, (3) the powder/acid mixture proportion, (4) the size of the filling, (5) the matrix material, (6) the relative humidity of the air, and (7) the time that passes from the moment the matrix is removed from the filling to the moment the filling has been protected by a coating of, for example, vaseline or varnish. In applying silicate cement in clinical conditions, an examination was made of factors 5 and 6.

Method. Only brand no. 2 was used in the experiment. The cement was mixed by hand to a consistency that was judged to correspond to normal consistency. In some cases a matrix of celluloid and in others a matrix of cellophane (with a thickness of 40 μ) was applied; a few fillings were placed without the use of a matrix, their surfaces being contoured and smoothed by means of the spatula. Rubber dam was employed for most of the fillings; in a small number of fillings, where it was possible to keep the operating field dry in any other manner, the rubber dam was omitted.

The matrix was removed from the surface of the fillings five minutes after mixing began. At this stage the cement had just passed the so-called nail test: excess cement is rolled into a ball (diameter about 2 mm) between two fingers and retained there until it is no longer possible by means of moderate pressure of the edge of a finger nail to produce a visible impression. Fifteen seconds after the removal of the matrix one or two lines were drawn with the already mentioned felt-tip marker on the surface of the filling in order to reveal any crazing that may have occurred.

Fillings which had not been covered by a matrix were examined at the same time as those that had been covered, viz. 5 minutes and 15 seconds after commencement of mixing.

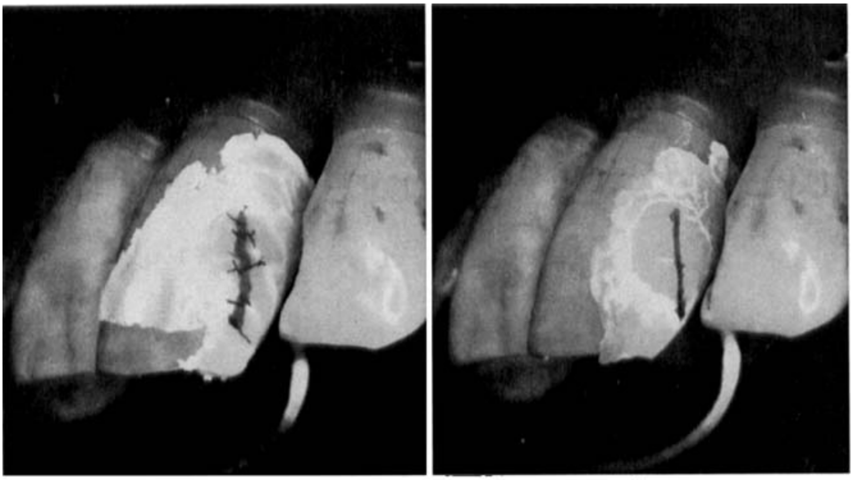
a b

Fig. 10. Silicate cement fillings placed successively in the same cavity; a rubber dam was used in both cases. a: the filling set under a celluloid matrix. b: the filling set under a cellophane matrix. The crazing test, conducted 15 seconds after the removal of the matrix, revealed that only the filling in fig. 10 a was crazed. The photographs were taken 10 minutes after the removal of the matrices; at this stage the filling in fig. 10 b showed obvious signs of crazing.

Results. The results are shown in Table III. Fig. 10 illustrates two fillings which had been placed successively in the same cavity under a rubber dam and otherwise in identical conditions except for the fact that the filling in fig. 10 a was made with the help of a celluloid matrix while the filling in fig. 10 b was made with the help of a cellophane matrix. Both fillings were photographed 10 minutes after the removal of the matrix by which time crazing had occurred in the latter of the two fillings also. The figures demonstrate the preventive effect of a cellophane matrix on crazing.

Table III

The crazing of silicate cement fillings under different conditions

Number of fillings	Type of filling	Matrix	Rubber dam	Crazing
5	Class 3	Celluloid	+	+
5	» 3	Cellophane	+	—
5	» 3	Celluloid	—	—
3	» 3	None	+	—
3	» 5	None	+	—

DISCUSSION

It is apparent from the studies described in the foregoing that silicate cement crazes in accordance with a specific phenomenological and causal pattern which in principle is identical for all the brands tested. Crazing is accompanied by a general change in the surface structure, resulting in increased opacity and easier discoloration, and which is possibly a contributory cause of the reduced resistance of the crazed cement to lactic acid.

For crazing to occur it is apparently necessary for the cement to dry by an evaporation process. Evaporation requires that the vapor pressure of the cement's liquid phase is greater than the vapor pressure of the surrounding atmosphere; from the experiments referred to in (f) it would seem that the vapor pressure of the liquid phase at the prevalent room temperature is less than that equalling a relative humidity of 85 % (approx. 18 mm Hg). The observation that cement does not appear to craze in the mouth when a rubber dam is not employed can be explained in the same way: the moisture from the exhaled air and from mucous membranes represents a sufficiently high vapor pressure to exceed the vapor pressure of the cement.

Cellophane's preventive effect on crazing is for the time being explicable only in tentative terms. One could imagine that the hygroscopic foil, acting as a semi-permeable membrane, specifically absorbs water from the cement and thus reduces the vapor pressure of the cement's liquid phase, since during the absorption of water there is an increased concentration of dissolved small ions and molecules in the cement. A reduction of the cement's vapor pressure would undoubtedly lead to a delay in the occurrence of crazing.

The fact that silicate cement does not craze during the period immediately after mixing (compare (a) and (e) above) is readily understandable since the cement at this stage is still very much in a plastic state; while a material retains only a small or moderate degree of plasticity, it is a fact that the phenomenon of crazing does not occur.

It is rather less easy to understand why silicate cement does not craze when the matrix is omitted (see (e)). It is possible that it can be explained in the same way as discussed during the above mention of the cellophane matrix by a reduction of the vapor pressure in the cement caused by evaporation, which can lead to an increase in the concentration of dissolved small ions and molecules in the liquid phase of the cement. A small number of observations not reported in the foregoing showed that the cement crazed at an unimpeded rate if the hygroscopic properties of the cellophane foil were reduced, or if the possibility open to the uncovered cement of evaporation was eliminated, e.g. by having the test specimens stored in an atmosphere with 100 % relative humidity until the crazing test was conducted at a stage of setting when by the normal method (see (a)) the specimens displayed early and intensive crazing.

The experiments described in (a) demonstrated that silicate cement does not craze, even after many hours of drying, once it has reached a certain age. The explanation here is no doubt that the tensile strength of the cement gradually becomes sufficient to resist the contraction stresses that arise during evaporation.

The diagram in Fig. 3 shows that silicate cement does not usually craze within 30 seconds of the removal of the matrix when the latter is removed at the Gillmore I time; regardless of the fact that the matrix can be removed from the cement at this stage without a risk of deforming the cement, a practical clinical method can scarcely be evolved from this observation to prevent the occurrence of crazing. The reason is in the first place that the Gillmore I time for a given cement can vary in practice, depending on the room temperature, temperature of the tooth, the powder/acid mixture proportion, the size and shape of the filling, etc., and in the second place that the Gillmore I time cannot always be ascertained with certainty for every single filling in clinical practice. One must therefore allow for a latent risk of crazing of all the cement brands studied.

On the other hand it would appear that crazing can be prevented in other ways, viz.: 1. by omitting the rubber dam; this method is applicable only in a limited number of instances since in many cases a rubber dam must be regarded as an indispensable means of keeping the operating area dry. 2. by not using a matrix; as a rule this method is quite applicable with cl. 5 fillings but not usually with cl. 3 fillings, where it is seldom possible by means of the spatula alone to adapt and contour the cement; it should be noted that a silicate cement filling can be covered, for example, with vaseline or varnish immediately after the application of the cement without damage to the latter. 3. by employing a cellophane matrix, provided that the filling is covered with vaseline or varnish immediately after the removal of the matrix.

Measurement of the depth of crazing cracks shows that the crazed surface layer of a silicate cement filling often cannot be removed by polishing the filling without detracting from its restoring function.

The demonstration of the reduced resistance of the crazed cement to lactic acid indicates that crazed fillings of silicate cement are perceptibly less durable than uncrazed fillings. The vastly reduced local marginal strength (Fig. 9) that results from acid corrosion in the crazing cracks is presumably also significant with regard to the durability of the filling.

The increased tendency of the crazed cement toward discoloration has scarcely much practical significance, in the first place because to a great extent discoloration seems to be reversible and in the second place because after a relatively short time in the mouth the great majority of silicate cement fillings are covered by a thin, porous layer of crumbled cement, the properties of which as regards discoloration are reminiscent of the crazed surface layer.

The slightly reduced tensile strength of the crazed cement can be assumed to have practical significance in certain unconventional types of fillings whose durability depends, among other things, on tensile strength (e.g. proximo-incisal fillings in front teeth).

SUMMARY

The crazing of silicate cement

The purpose of the present work has been to discover by means of laboratory studies the laws determining the crazing of silicate cements and to investigate the possible clinical significance of this phenomenon. A small number of

fillings were made of one of the eight brands included in the study to check the validity of the results of the laboratory work. No discrepancy was found between the clinical and the laboratory findings.

All the cements showed a latent tendency toward severe crazing immediately after the removal of the matrix when this was done at about the Gillmore I time, i.e. a stage of setting when the cement is no longer adhesive nor shows a perceptible plasticity.

In practice, crazing can be prevented by one of the following three methods: 1. omission of the matrix, 2. use of a cellophane matrix instead of the usual ones of celluloid, cellulose acetate or metal, or 3. omission of a rubber dam.

Crazed silicate cement fillings are considerably less resistant to diluted lactic acid than uncrazed fillings are, and they will probably also have a correspondingly reduced durability. Crazed cement is very susceptible to discoloration but the latter is largely reversible. The flexure strength of silicate cement is only slightly less than that of uncrazed cement. The cracks resulting from crazing are so deep (0.15 to 0.20 mm) that they cannot be eliminated by an acceptable polishing of the crazed filling.

RÉSUMÉ

APPARITION DE CRAQUELURES À LA SURFACE DU CIMENT AU SILICATE

Des études de laboratoires sur l'apparition de craquelures à la surface de ciments au silicate ont été effectuées, dans le but de mettre en lumière le mécanisme de ce phénomène et d'étudier l'importance clinique pratique de l'apparition de ces craquelures. De plus, un nombre limité d'observations cliniques ont été réalisées en utilisant un des produits, dans le but de contrôler la valeur des résultats des études de laboratoires. Aucune divergence n'a été constatée entre la façon dont le ciment se comportait au laboratoire et en clinique.

Avec tous les ciments étudiés, on a constaté que des craquelures avaient tendance à se produire immédiatement après l'enlèvement de la matrice, lorsqu'on détachait celle-ci à peu près au moment où la prise avait atteint le degré Gillmore 1, c'est-à-dire un degré où les ciments cessent d'adhérer et de présenter une plasticité appréciable.

En pratique, on peut prévenir l'apparition de ces craquelures de trois manières différentes: 1) en n'employant pas de matrice, 2) en employant une matrice de cellophane au lieu des matrices habituelles de celluloïd,

d'acétate de cellulose ou de métal, ou 3) en n'employant pas la digue de caoutchouc.

Les obturations craquelées présentent une nette réduction de résistance envers de faibles solutions d'acide lactique par rapport aux obturations sans craquelures, et leur durée en bouche, de même, sera probablement médiocre. La teinte du ciment craquelé s'altère très facilement, mais cette alteration est dans une assez grande mesure réversible. Les craquelures causent une réduction modérée de la résistance du ciment à la flexion. Etant donné la profondeur des fissures dans le ciment craquelé (0,15—0,20 mm), il n'est pas possible de les faire disparaître en polissant l'obturation.

ZUSAMMENFASSUNG

KRAQUELIERUNG VON SILIKATZEMENT

Es sind über die Kraquelierung von Silikatzementen Laborversuche ausgeführt worden, um die Gesetze klarzulegen, die für diese Erscheinung bestimmend sind, und um die praktisch-klinische Bedeutung der Kraquelierung zu untersuchen. Ausserdem wurde mit einem der Fabrikate eine beschränkte Anzahl klinischer Observationen vorgenommen, um den Wert der Ergebnisse aus der Laboruntersuchung zu kontrollieren. Zwischen dem Verhalten des Zements im Laboratorium und in der Klinik konnte keine Diskrepanz festgestellt werden.

Alle untersuchten Zemente zeigten eine latente Neigung zur Kraquelierung unmittelbar nach der Entfernung der Matrize, wenn dies etwa um die Gillmore-l-Zeit geschah, d.h. bei einem Stadium der Abbindung, in dem die Zemente nicht länger klebend oder merkbar plastisch sind.

Einer Kraquelierung lässt sich praktisch auf drei verschiedene Arten vorbeugen: 1) indem man keine Matrize verwendet, 2) indem man anstatt der üblichen Matrize aus Zelluloid, Zelluloseazetat oder Metall eine Zellophanmatrize verwendet oder 3) indem man kein Kofferdam verwendet.

Kraquelierte Füllungen sind schwachen Milchsäurelösungen gegenüber wesentlich weniger resistent als nicht kraquelierte Füllungen und ergeben vermutlich eine entsprechende geringe Haltbarkeit im Munde. Der kraquelierte Zement verfärbt sich sehr leicht, jedoch ist die Verfärbung in weitem Masse reversibel. Die Kraquelierung bewirkt eine moderate Reduktion der Biegefestigkeit des Zements. Die Kraquelierungsrisse haben eine solche Tiefe (0,15—0,20 mm), dass sie sich durch Polieren der Kraquelierten Füllung nicht entfernen lassen.

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Address:
Department of Technology
The Royal Dental College,
160, Jagtvej, Copenhagen Ø,
Denmark