NATIONAL BUREAU OF STANDARDS REPORT

7564

Progress Report

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by

Gert Forum Petersen

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Marginal Defects in Amalgam Fillings as a Result of Thermal Expansion and Flow

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U. S. DEPARTMENT OF COMMERCE

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MARGINAL DEFECTS IN AMALGAM FILLINGS AS A RESULT OF THERMAL EXPANSION AND FLOW

Abstract

Flow of amalgam out of a cavity as a result of the large thermal expansion of amalgam compared to tooth structure is proposed as one mechanism for the occasionally observed extrusion of amalgam restorations in service. Extrusion was observed experimentally on amalgam "fillings" in glass molds when cycled between 23° and 65°C several thousand times with a frequency of about 1 minute or when cycled only a few times with a much longer period. Additional data are needed to determine definitely the relationship between extrusion and temperature cycling of the amalgam.

1. INTRODUCTION

It has often been observed that older amalgam restorations show marginal defects, Figure 1. The amalgam is often raised above the tooth surface. There may be a fissure between the cavity wall and the filling and often fractures are seen in the marginal angle of the filling.

Improper cavity preparation and improper handling of the amalgam as well as delayed expansion in amalgam are, without doubt, the reasons for many of these defects. Even with good technics, restorations often show these defects after some years in service.

After a proposal made by Knud Dreyer Jørgensen, an investigation of this phenomenon was started in 1959 at the Royal Dental College of Copenhagen. The present investigation is a continuation of that work.

When a tooth with an amalgam filling is heated, the amalgam will expand to a greater extent because of its higher thermal expansion coefficient. Also, the filling will expand more rapidly since amalgam is a better heat conductor than is tooth structure. Therefore, a pressure will be exerted on the amalgam by the surrounding tooth structure. The amalgam will tend to flow out of the cavity to a degree depending on the flow characteristics of the amalgam at the temperature to which it is heated and on the duration of the heating. When tooth and filling again cool down to mouth temperature or lower, a space will arise between the filling and the cavity wall if flow has occured at the higher temperature.

The coefficient of thermal expansion for tooth structure across the crown is about 11×10^{-6} mm/mm°C and for amalgam about 25×10^{-6} mm/mm/°C, [1]. For a filling 8 mm in diameter and a difference in temperature of 50°C, the linear difference in expansion will be $(25-11) \times 8 \times 50 \times 10^{-6} = 5.6$ u, or 2.8 u on each side of the filling. This is the size of the space which will be obtained if the amalgam flows until all pressure on the filling is relieved.

If the space between amalgam and tooth structure is partially filled with some sort of material (food perhaps or corrosion products), the filling will have insufficient space to expand freely when it is reheated. Again there will be a pressure, the filling will flow and a new fissure will arise when the filling is again cooled. In this way it is

presumed that repeated thermal insults will accumulate and produce a macroscopic fissure.

It can be predicted that the eating habits (use of hot and cold food, coffee, icewater, etc.) will have great influence on where and to what degree the mentioned phenomenon will occur. This circumstance and the way the space is filled in the mouth are nearly impossible to imitate in the laboratory; thus, a quantitative investigation would be difficult. It is, however, possible to make a qualitative study showing that the phenomenon does occur when a restoration is cycled through a temperature range a large number of times.

2. EXPERIMENTAL PROCEDURE

An experiment was designed to determine whether growth of amalgam out of a cavity could be produced under laboratory conditions by the thermal expansion-flow mechanism. For this purpose cavities were cut in pieces of pyrex glass. The glass molds containing the fillings were then cycled between two water baths at different temperatures and examined for extrusion of the amalgam.

In 12 pyrex glass pieces 20 X 20 X 9 mm, cavities 8 X 8 mm were drilled with ultrasonic equipment to a depth of 3.9 to 5.2 mm. (One cavity, No. 3, had a depth of 5.9 mm). The sides of the cavity were plane and at right angles to the surface; the corners were sharp. The bottom was plane and perpendicular to the sidewalls. The bottom edges and corners were rounded. After the drilling of the cavity, the surface of the glass piece was ground and polished so nearly all scratches in the cavity edge disappeared and the edge was sharp and smooth. Excepted from this was glass mold No. 12 where some defects were left to simulate overhang on a filling. After having been cleaned with water and alcohol, each cavity was dried and examined with a magnifying glass, and a description of any irregularities was recorded.

The alloys used and their compositions are shown in Tables 1 and 2 [2]. Cavities No. 1 to 6 were filled with Alloy A and cavities No. to 12 with Alloy C.

An 8 to 5 mercury-alloy ratio was used for both alloys. The mercury and alloy were weighed on a torsion balance to the nearest 10 mg. Trituration was done mechanically using a Crescent Wig-L-Bug amalgamator. Time of trituration was 7 seconds for Alloy A and 13 seconds for Alloy C. Excess mercury was expressed from the entire mix through a squeeze cloth. The specimens were made by handpacking, using a 1.5 mm plugger with a force of approximately 3.5 pounds. Two mixes were made for each cavity. The second mix was started immediately after the first portion was packed. The cavity was over filled and stored 1 week in water at 37°C. The fillings were then ground down to the level of the glass mold by abrasive and water on a glass plate and polished with chalk in water on a rotating polish wheel. The fillings were examined with a magnifying glass, and a description of each was recorded.

Rubber base impressions were taken of all 12 specimens in one tray and a model was poured in stone, Figure 2. In addition pictures were taken with flash illumination of specimens No. 1, 4, 8 and 10. Specimen No. 1 is shown in Figure 3.

To heat and cool the specimens, an apparatus was made having one basin with hot and a second basin with cool water. Each basin consisted of an outer and an inner container. The volumes of the inner containers were about 1 liter each. The temperature of the hot water was held at 65±2°C and the cool water at 23±2°C. Connecting tubes maintained a constant water level in all basins.

The specimens were placed on a plastic plate and, by a gear and rack system, were moved from the warm to the cool water and back again at a rate of 72 cycles per hour. The duration time in each of the baths was 10 seconds with an intervening period of 15 seconds.

The plastic plate was only a little smaller than the inner containers and was provided with two holes which gave a good stirring effect when the plate was moved up and down. All parts in contact with the water in the inner container were made of Teflon, methyl methacrylate or polyethylene to avoid possible electrical corrosion from metals. To both the cool and the warm baths were added particles of aluminum oxide, 30 grams in each bath, with particle sizes of 5, 1 and 0.3 μ. Specimens No. 1, 2, 3, 4, 7, 10, 11, and 12 were placed on

the plastic plate and heated and cooled 25,700 times. Specimens No. 6 and 9 were kept in the warm water as controls. Specimen No. 8 was stored in air at room temperature, and Specimen No. 5 was heated about 1 hour and cooled about 1/2 hour in the water baths containing aluminum oxide particles about 30 times.

The specimens were taken from the water, examined with a magnifying glass and described after 700, 2,000, 11,300, 15,500, 20,000 and 25,700 cycles. Pictures were taken with small angle illumination of both plaster models and specimens after the experiment was finished showing changes in the marginal zone and accumulation of particles in the edge zone of the fillings.

The cycling procedure was stopped over the weekends and the specimens were stored in the cool bath. Both baths were allowed to come to room temperature during the weekends resulting in the control specimens being cooled to room temperature, No. 6 three times, No. 9 two times.

3. RESULTS

After a few cycles, water was observed between the fillings and the glass walls. On cooling a filling and the glass mold in water and afterwards heating them in air, small drops of water were seen to appear along the edge of the filling as reported by Nelsen, Wolcott and Paffenbarger [3].

The specimens were described at various periods during the cycling procedure as follows:

After 700 cycles Nearly all fillings show some yellow-brown discoloring between filling and glass about 1/3 of the way down from the surface. No. 2 and 10 show some powder accumulations along the margin of the filling mostly in shape of hemispheres.

Before the start of the experiment there was a small vertical crack in the corner close to the filling in mold No. 2 in an 8 o'clock position. The crack is now much greater. In glass mold No. 3 is seen a diagonal crack in the glass in an 11 to 5 o'clock position.

No others changes are seen.

After 2,000 cycles Specimens No. 1, 4, 10 and 11 show powder retained along the margin of the filling, Figure 4. No. 10 shows a little new broken piece in the cavity edge in an 8 o'clock position.

No other change is seen.

After 5,600 cycles Control specimens No. 6 and 9: The fillings are strongly discolored, gray-blue and yellow-brown. Both fillings have extruded somewhat out of the cavity, No. 9 most. Powder is retained along the margin of both fillings. Both glass molds are cracked. No. 6 is cracked from 2 to 8 o'clock completely through the glass, from 11 to 5 o'clock only 2/3 of the way out to the edge of the glass and only to the depth of the filling. In No. 9 an open crack from 2 to 8 o'clock goes all through the glass. In the 8 o'clock position 2 mm from the filling the crack is about 90 μ wide. (After 7,400 cycles No. 9 and after 10,500 cycles also No. 6 fell in two pieces and were taken from the water.)

After 9,100 cycles Glass mold No. 3 is now in two pieces. The upper 1/3 of the side surfaces of the amalgam filling is discolored.

After 11,300 cycles All the fillings are discolored gray-blue and yellow-brown. Only where powder is retained is the amalgam silver-white. All the fillings have powder retained along the margin. Specimens No. 1 and 2 show some raising of the filling; it is possible to feel an edge but it is difficult to observe it visually.

On No. 12 the overhang in the 8 o'clock position is clearly elevated and the whole filling shows some raising. Powder is retained under the overhang.

After 15,500 cycles All the specimens show powder retained along the margin and raising of the filling, Figure 5. The overhang on No. 12 is very decidedly curved up, Figures 6a, 6b.

After 20,000 and 25,700 cycles The extrusion process continues for all specimens without any other changes evident, Figure 7.

Specimen No. 5, that had been heated and cooled for long periods (1 hour and 1/2 hour) about 30 times shows nearly the same extrusion as the rest of the specimens.

All the fillings that had been heated and cooled showed extrusion of the amalgam and retention of powder along the margin, Figures 2, 3, 5, 7 and 8. Specimen No. 8 which had been kept at room temperature showed no indication of dimensional change, Figure 9. It was difficult to distinguish any differences in the extrusion between the two alloys used. Three of 6 glass molds were cracked and 1 showed beginning cracking using Alloy A. One of 5 glass molds was cracked using Alloy C. All fillings definitely showed discoloring. Glass mold No. 11 was split to permit inspection of the filling and mold. Powder was seen retained on the sidewalls of both filling and glass, Figure 10.

The cracked glass molds raised the question as to whether the same thing could happen in natural teeth. Over-extended cavities (Class I and Class I-II) were therefore made in 9 extracted teeth. Since extraction, these teeth had been stored in distilled water at a temperature of about 8°C. The cavities were filled using the same technic as that used for the glass molds; No. 1-5 with Alloy C and No. 6-9 with Alloy A. The teeth were stored 1 week at room temperature in water, ground and polished wet and placed in tapwater at 67°C for 160 hours.

The teeth were examined at intervals. Only one (No. 1) showed a crack in the tooth structure. After only 14 hours a white material was seen along the margin of the fillings, especially where the fillings were somewhat insufficient. After 100 hours the white material was seen along the margins of all the fillings often in the shape of hemispheres, Figure 11. No further cracking was seen. In this experiment no attempt was made to study the effect of alternate heating and cooling.

Flow of the two amalgams used was determined at high temperatures. Except for the temperature and the age of the specimens the test was carried out in accordance with A. D. A. Specification No. 1. Flow tests were made on 1 week old specimens in air. For each amalgam, with a few exceptions, 2 tests were made at 37°C, 47°C, 57°C and 67°C. The flow was measured with both screw micrometer and dial gauge. The results are shown in Figure 12.

4. DISCUSSION

Insufficient data were obtained in this investigation to answer all questions concerning the clinical observation that amalgam restorations sometimes appear to grow out of the cavity. It was found, as predicted, that amalgam fillings in glass cavities do extrude out of the cavity when cycled between room temperature and 65°C a large number of times in a medium containing small particles in suspension. It was also found that the flow of amalgam at 65°C is much greater than at room temperature. These results are consistent with the proposed mechanism that extrusion of a filling is produced by a combination of differences in thermal expansions for tooth and amalgam, flow in the filling material and a blocking by food and corrosion products of the space opened between cavity wall and filling on cooling. Accumulation of material along the margin of the filling also, when no particles were present, seems to indicate that corrosion phenomena can be an additional factor involved in filling in the space and perhaps also for the breakdown of the margin by weakening the amalgam.

Some doubt as to whether or not cycling of the temperature is the determing factor in the extrusion of the amalgam is raised by data on specimens which were cycled only a few times. Extrusion was observed on one specimen in a glass mold which was cycled 30 times with a period of 1 1/2 hours and on two specimens which were maintained at 65°C throughout the experiment with the exception of two or three periods at room temperature. However, since the flow of amalgam takes place slowly, a few long period cycles may be equivalent to a large number of short cycles.

The possibility that extrusion of the filling may be related to the delayed expansion produced by contamination with moisture [4] should not be overlooked. Although delayed expansion normally occurs only in zinc containing amalgams contaminated during mixing, it may be possible that specimens which do not exhibit delayed expansion at room temperature would do so at a higher temperature.

It is probable that the large difference in thermal expansion between tooth structure and amalgam and a cumulative effect resulting from a filling in of the space between tooth restoration could result in fracture of the

tooth. In fact a fracture was noted in one extracted tooth which has been stored in water at 67°C after a large amalgam restoration had been placed in it. It would seem, therefore, that caution should be exercised in the use of very large amalgam restorations.

Further studies should be made of the white deposits observed around the edge of the amalgam restorations. Although these appeared to be corrosion products no attempt was made to identify them in this study.

5. SUMMARY

Extrusion from the cavity was observed on amalgam fillings in glass molds when they were cycled between room temperature and 65°C. This is believed to result from flow produced by the pressure exerted by a low expansion cavity in which the high expanding amalgam is confined. It is thought that a cumulative growth effect is produced as a result of corrosion products or other materials filling in the space between amalgam and cavity on cooling, but sufficient data to verify this mechanism have not yet been obtained.

6. REFERENCES

1. Souder, W. and Paffenbarger, G. C. Physical properties of dental materials. Circular of the National Bureau of Standards C 433, United States Government Printing Office, Washington, D. C. (1942).

2. Demaree, N. C. Properties of dental amalgam made from spherical particles. National Bureau of Standards Report 7193. June 30, 1961.

3. Nelsen, R. J.; Wolcott, R. B. and Paffenbarger, G. C. Fluid exchange at the margins of dental restorations. J.A.D.A. 44:288 March 1952.

4. Schoonover, I. C.; Souder, W. and Beall, J. R. Excessive expansion of dental amalgam. J. A. D. A. 29:1825 Oct. 1942.

TABLE 1

Amalgam Alloys Used

Alloy	Manufacturer	Batch No.
A New True Dentalloy	The S. S. White Dental Manufacturing Co.	16660342
C 20th Century Regular Alloy	The L. D. Caulk Co.	31E60

TABLE 2

Chemical Composition of Alloys Used*

	Composition in %			
Alloy	Silver	Tin	Copper	Zinc
A	70.8	25.8	2.4	1.0
C	70.0	26.0	3.5	0.5

* Data from Demaree [2] (different batch numbers)

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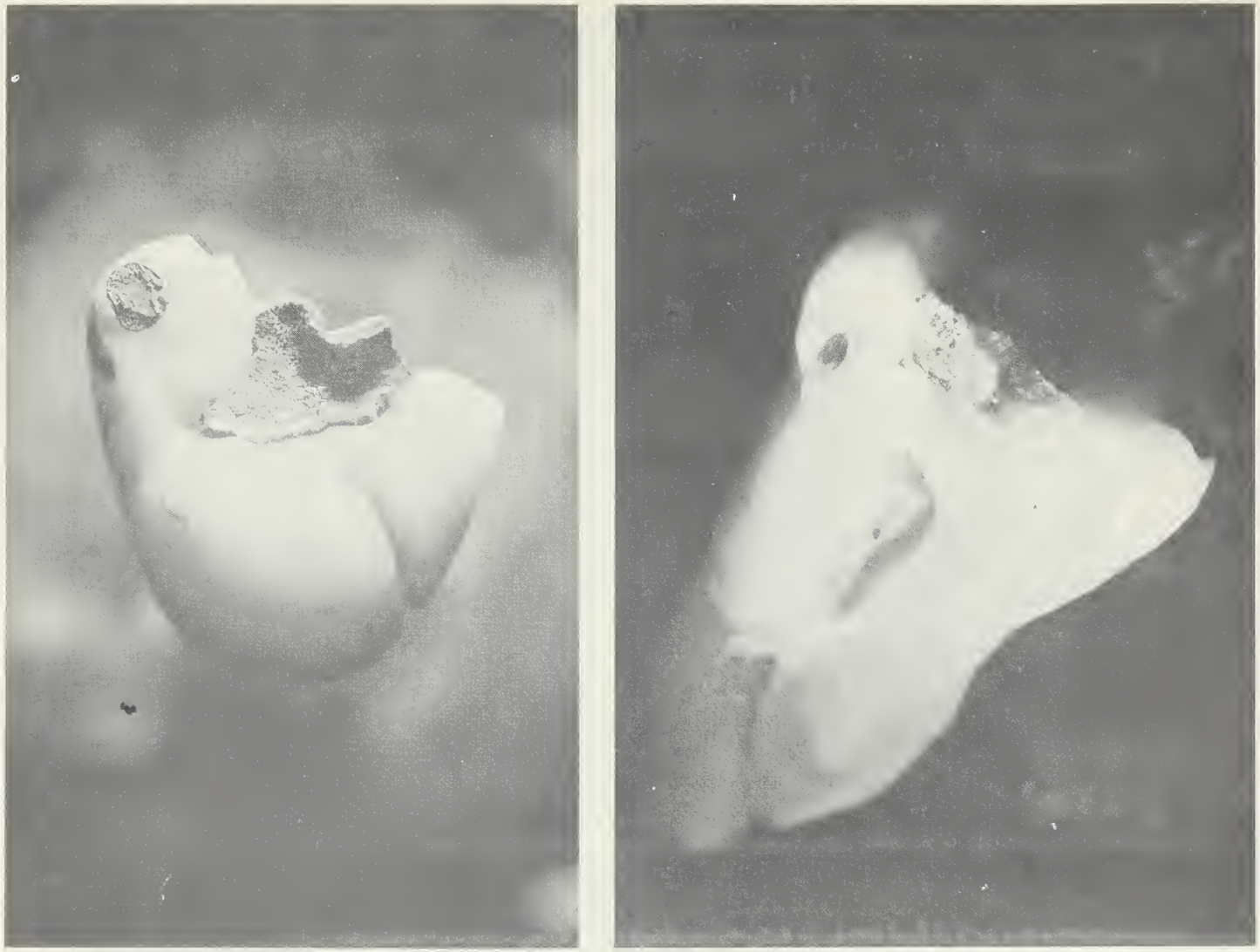

Figure 1: Two views of an amalgam filling in an extracted tooth showing defective marginal zone and discoloration of the side of the filling. The tooth was fractured after extraction to permit inspection of the amalgam.

Figure 2: Stone model of all 12 glass molds with specimens before start of temperature cycling. The picture was taken with low angle illumination

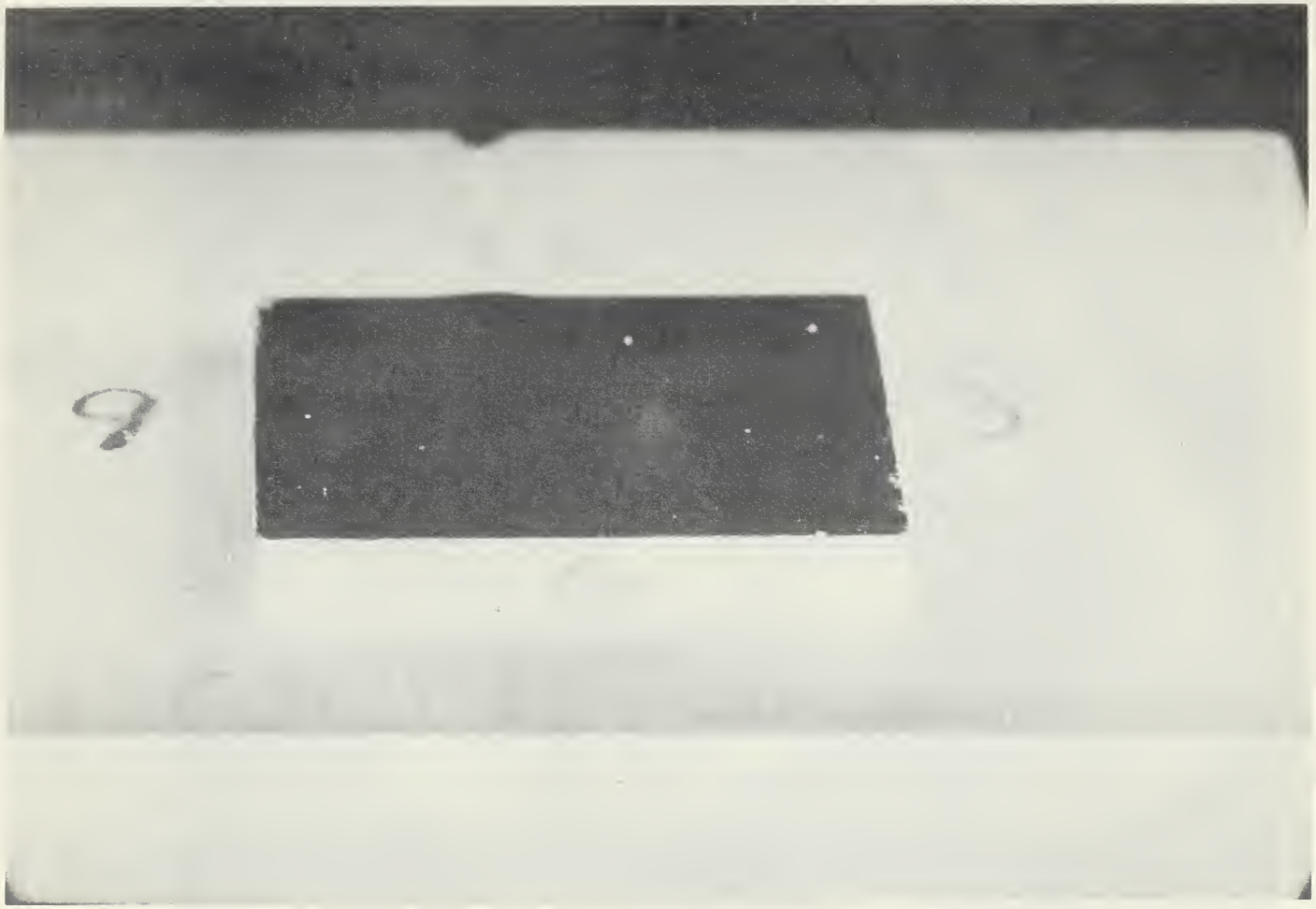

Figure 3: Glass mold with specimen No. 1 before start of temperature cycling (seen from a 6 o'clock position).

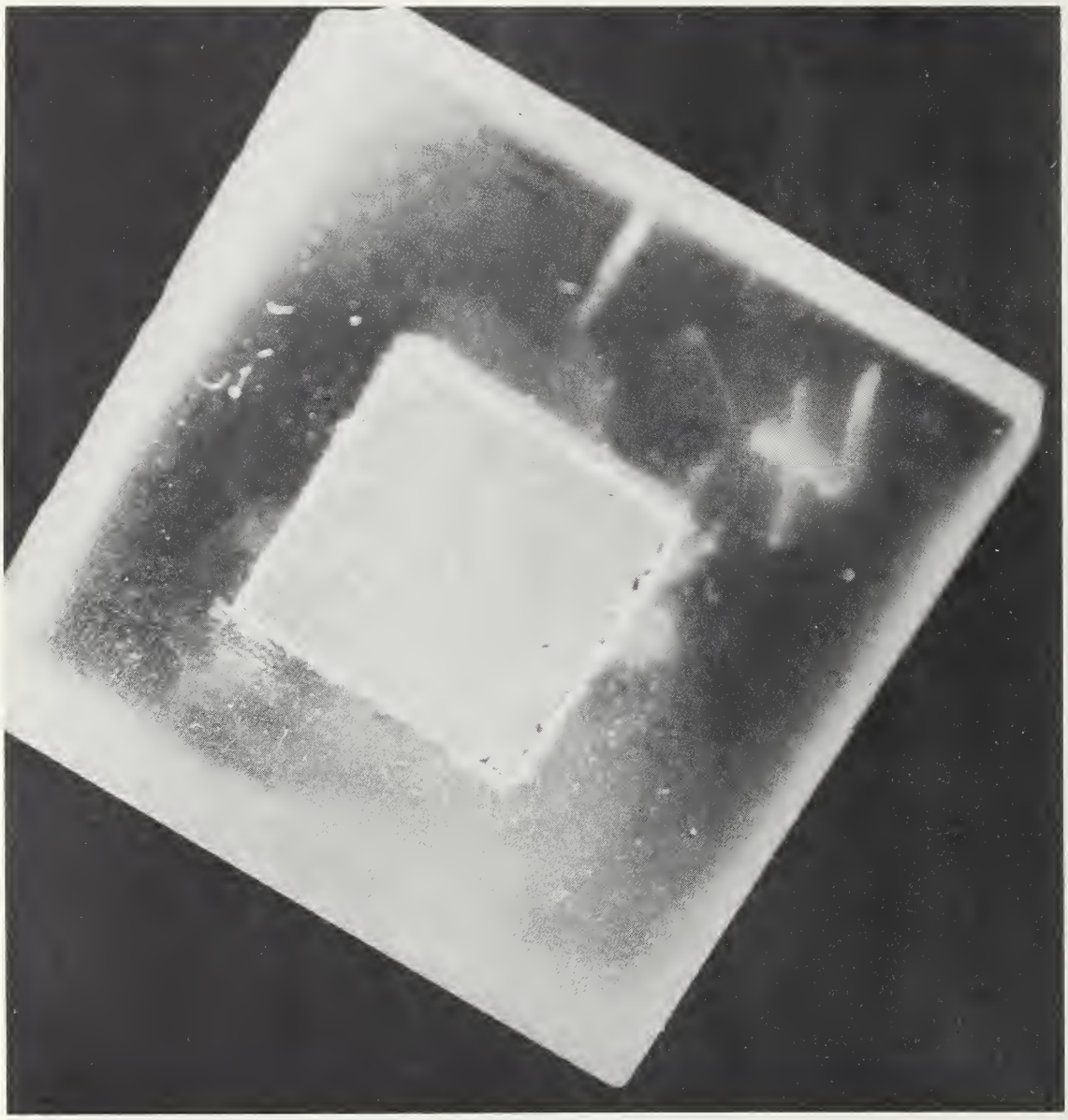

Figure 4: Powder accumulation along the margin of the filling (specimen No. 4) after 2,000 cycles.

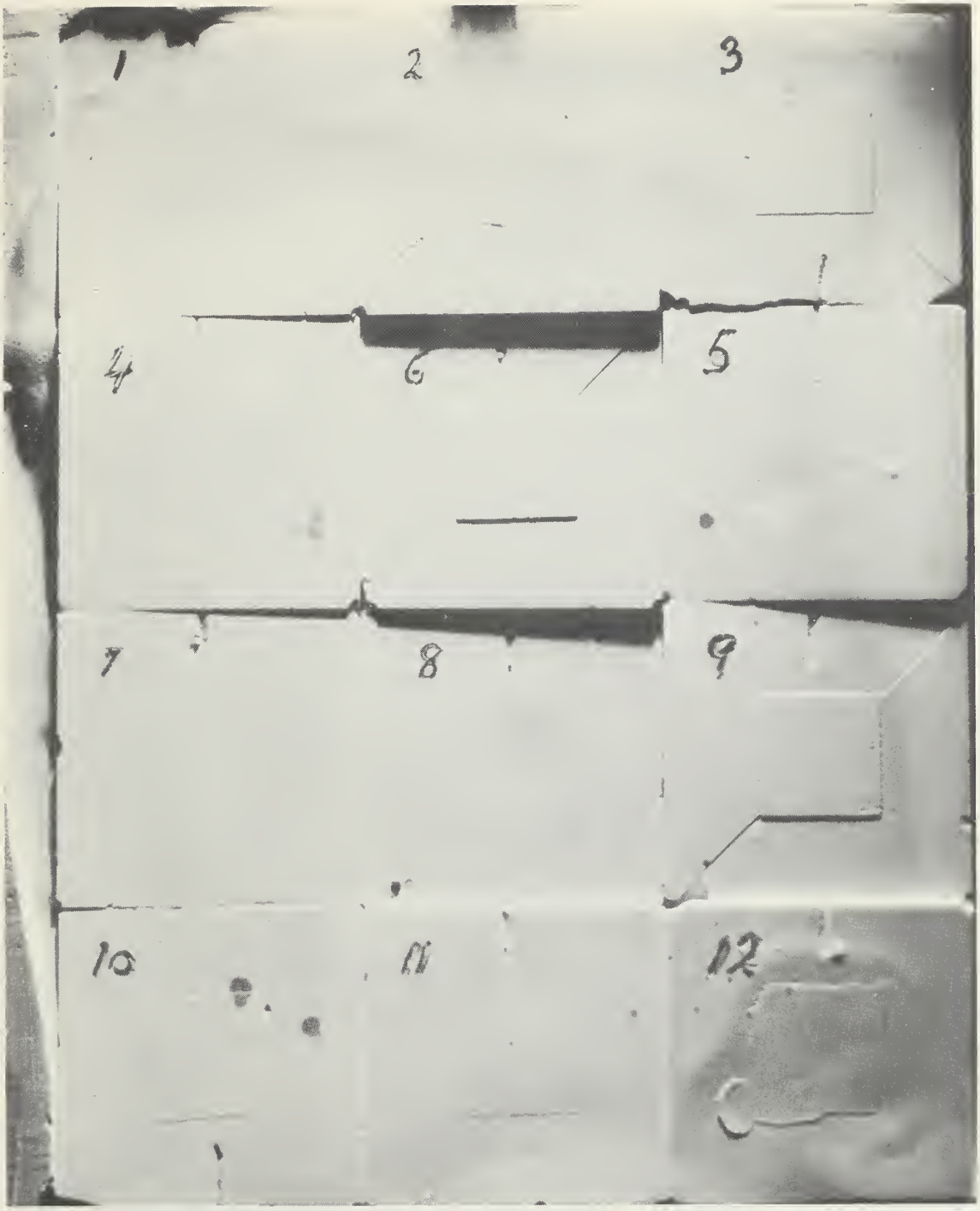

Figure 5: Stone model of glass molds and specimens after 15,500 cycles. The specimens in the broken glass molds are loose and raising of the fillings is therefore not comparable to the others. Numbers 5 and 8 have not been subjected to any temperature cycles. Raising or extrusion of the filling is especially seen on Numbers 7, 10, 11 and 12.

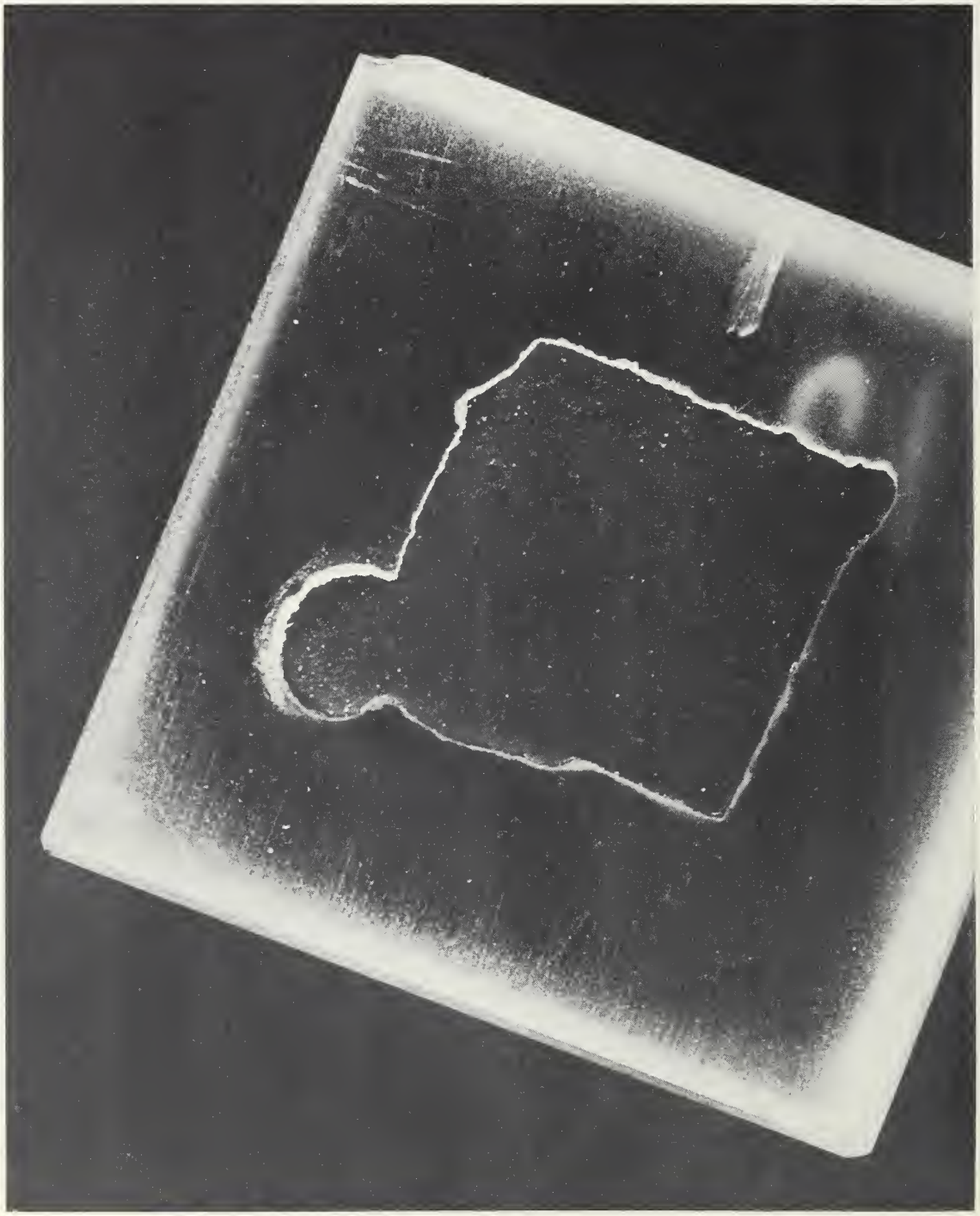

Figure 6a: Glass mold with specimen No. 12 after 15,500 cycles. The filling (especially the overhang at 8 o'clock) is raised and curved. Powder is retained along the margin of the filling.

Figure 6b: Specimen No. 12. Raising of the overhang in an 8 o'clock position is apparent.

Figure 7: Stone model of glass molds and specimens after 20,000 cycles. No. 8 had been kept at room temperature. All other specimens show extrusion. Powder accumulation is seen on No. 4.

Figure 8: Specimen No. 1 after 25,700 cycles (seen from a 6 o'clock position) showing raising of the filling. (Compare with Figure 3).

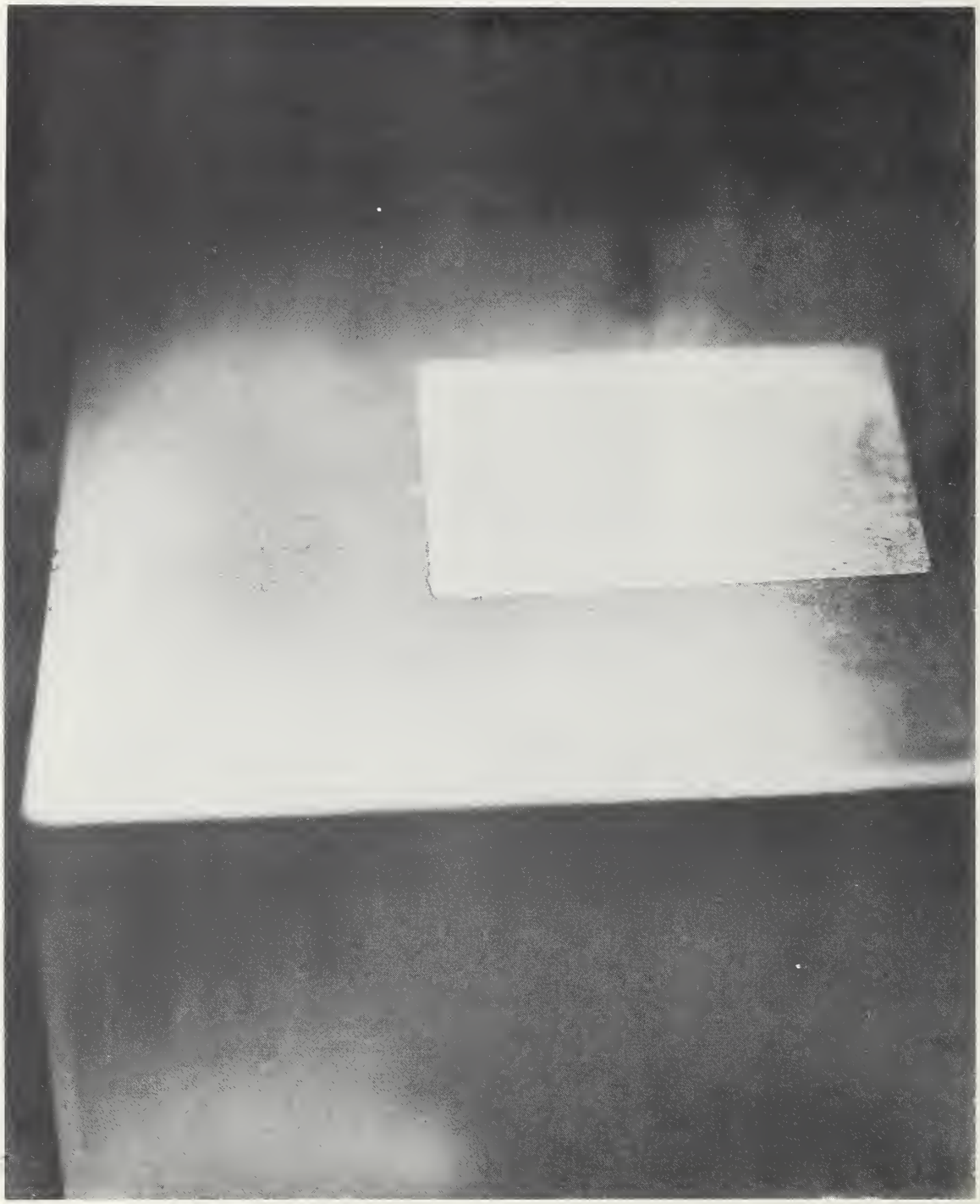

Figure 9: Glass mold with specimen No. 8. This specimen had not been heated. No raising is seen and the margin is smooth without fracture.

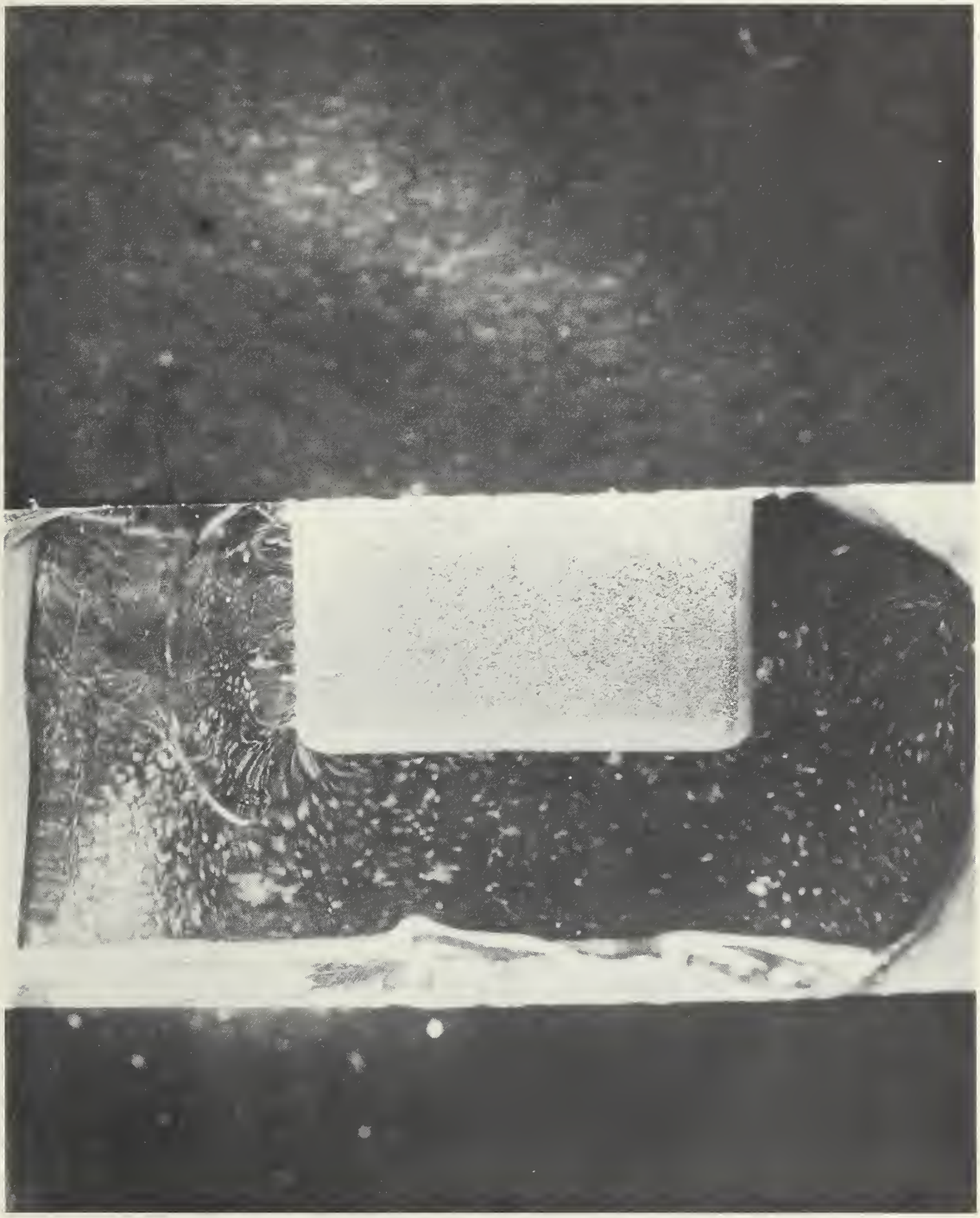

Figure 10: Sidewall of glass mold No. 11 showing powder retention on the upper 1/3 of the wall.

Figure 11: Tooth with amalgam filling made with the same techniques as the fillings in the glass molds and heated 160 hours at 67°C. White material is seen along the margin. Since there were no particles in the water, the material is assumed to consist of corrosion products.

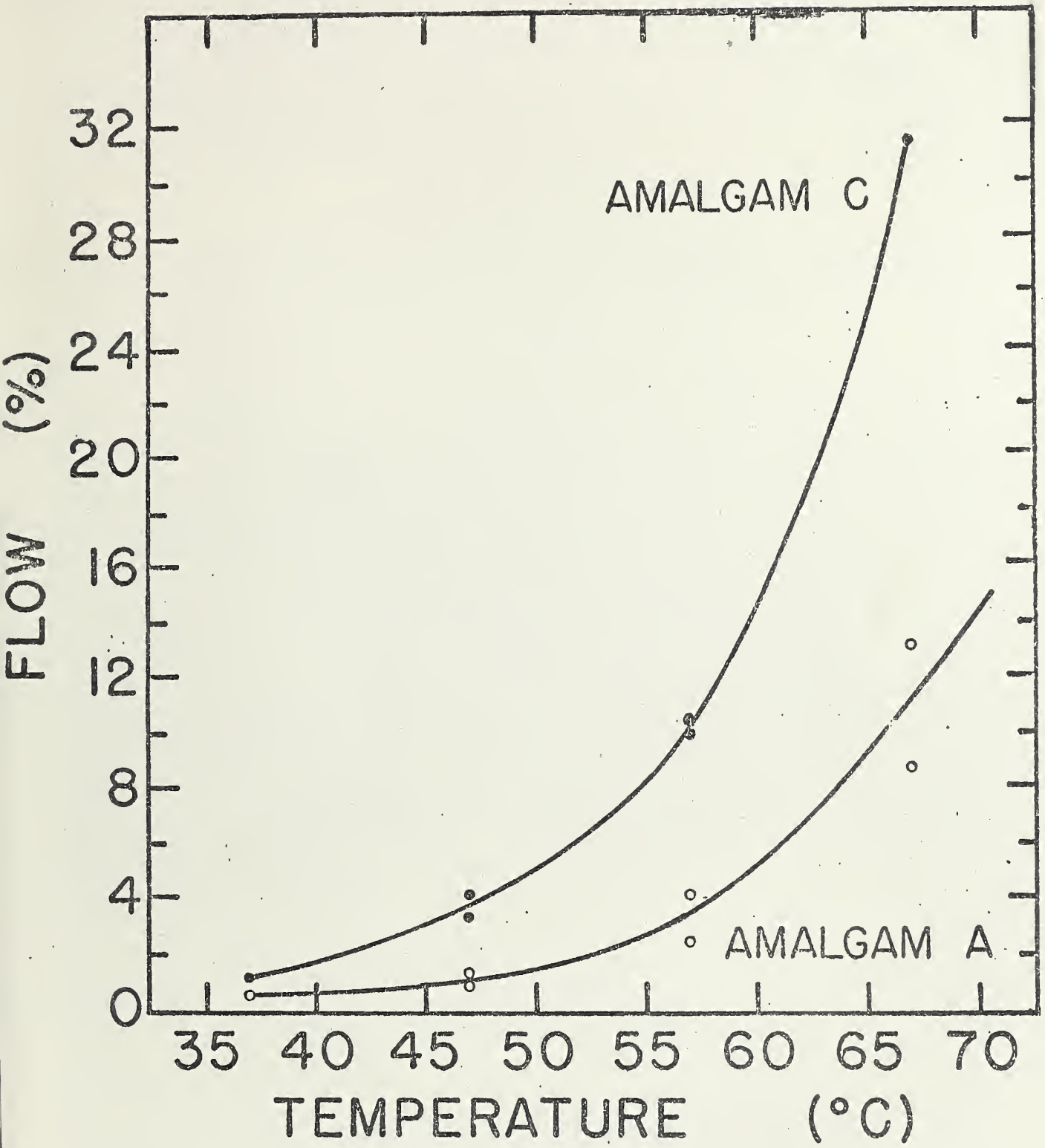

Figure: Flow of amalgam at elevated temperatures. The points represent single specimens.

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