Studies on the Tensile Strength of Dental Amalgams by the Application of Diametral Compression Test
Part 2 Effects of Manipulative Variables

by

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1. Introduction

The tensile strength property of a dental amalgam is recognized to be of a highly clinical importance and yet the volume of researches on this specific aspect of amalgam is much more limited than those dealing with other aspects of amalgam. One reason for a relative dearth of research efforts is that the preparation of test specimens possessed of homogenous quality is very difficult to be used for the dumb-bell form specimen hitherto in use, with an attendant wide scatter of data. In other words, the validity of a test method for this kind of fragile material needs to be reconsidered.

In our previous report, Part 1[1], we confirmed the effectiveness of diametral compression test for the purpose of testing the tensile strength of amalgam, which enables the preparation of test specimens far easier and necessary data to be obtained with a high degree of accuracy.

In the present study, efforts were directed to possible effects of various manipulative variables that would come to bear on the efficient use of this diametral compression test.

2. Material and Method

2.1 Material and Hg-alloy ratios.

Two kinds of amalgam, conventional and spherical, were selectively used for comparative purposes. They are given in Table 1 together with Hg-alloy ratios employed.

Table 1

Amalgam	Batch No.	Hg-alloy ratio
Shofu Spherical Alloy	No. 69	0.7, 0.85, 1.0
Shofu Micro Alloy	No. 43	1.0, 1.2, 1.4

Test specimens were prepared in the same manner as in our previous Part 1, though experimental items to be described below were of course different.

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2.2 Kind of amalgamators and trituration time.

Three amalgamators were used: G-C Luna IIB, Shofu Mixer and S.S. White No. 3 Mixer. With G-C and S.S. White mixers, a comparison was made of the presence or absence of metal ball or pestle. Trituration was effected in 7 different lengths of 5, 10, 15, 20, 30, 45 and 60 seconds.

2.3 Increments used.

In an effort to find out effect of the number of thrusts on amalgam mix in process of condensation, the mix was divided in 1, 2, 4, 8 and 16 increments each for which a total of 80 thrusts was administered.

2.4 Delayed condensation.

Some kind of effect is bound to occur in the amalgam mix between an interval from the finish of trituration to the start of condensation when exposed at room temperature of 23°C. Therefore, the mix was purposely left exposed to room temperature for 7 different intervals: 0 (no time lag between finish of trituration and start of condensation), 1, 1.5, 2, 3, 4 and 5 minutes.

2.5 Condensation time.

Under this heading, condensation time was varied from 3 to 10 minutes so that effect of condensation time on the tensile strength might be more exactly established.

2.6 Condensation pressure and environmental temperature.

That condensation pressure will largely influence the resultant physico-chemical properties of amalgam is universally accepted. Here effects of 5Kg/cm^2, 10Kg/cm^2, 20Kg/cm^2, 30Kg/cm^2 and 60Kg/cm^2 were comparatively examined. Besides, effects of room temperature of 23°C and oral environmental temperature of 37°C were also looked into, in their bearings on the tensile strength.

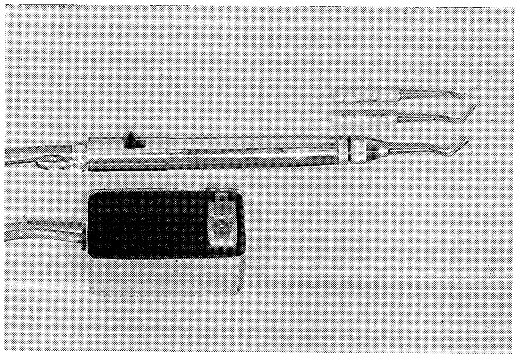

Fig. 1 Mechanical Condenser "Auto Plugger."

2.7 Mechanical condenser.

Shofu Dental Mfg. Co., Kyoto, recently marketed "Auto Plugger" (Fig. 1),

especially designed for the mechanical condensation of spherical amalgam. This apparatus uniformly packs amalgam by means of electric vibrations. For our purposes, the point of this plugger was made to be 2.5cm in diameter, which is true of usual condensing pluggers. With the Auto Plugger, 100, 300, 500, 1000 and 1500g loads were applied.

3. Results and Discussion

3.1 Mercury-alloy ratio.

Fig. 2 tabulates effect of various Hg-alloy ratios on the tensile strength of amalgam. Within the range of ratios used in the study, however, their effect on the resultant tensile strength was hardly significant. It was established that tensile strength of spherical amalgam was much larger than that of conventional amalgam in every Hg-alloy ratio; the former packed with a small condensation pressure proved stronger than the latter packed with a large pressure.

A Hg-alloy ratio, a consideration of highly clinical significance, is directly related to the compressive strength: when the amount of mercury at trituration is less, it will produce less residual mercury and result in higher compressive strength[2–5]. But according to SWEENEY[6], there was not observed a large difference within a large variation of Hg-alloy ratios from 1.0 to 10.0. NAGAI and his associates [7] similarly concluded that, within a range of clinically usable Hg-alloy ratios, the ratio did not materially influence the compressive strength of either conventional or spherical amalgam. The findings of the present study demonstrated the same truth pertaining to the tensile strength.

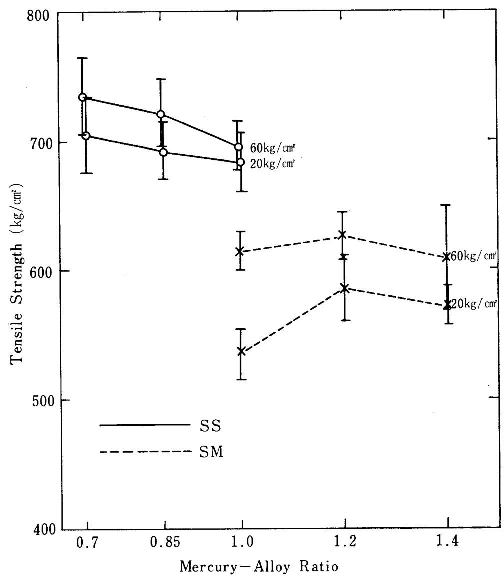

Fig. 2 Effect of Mercury-Alloy Ratio on Tensile Strength of Amalgam

3.2 Kind of amalgamators and trituration time.

The mechanical movement of a capsule attached to mechanical mixers was studied by means of the storoboscope (MSX-IA, manufactured by Sugawara Laboratory).

The results were as follows.

Mixer	Capsule movement
G-C Luna IIB	2,899 r.p.m.
Shofu Mixer	2,843 r.p.m.
S.S. White No. 3	1,362 r.p.m.

Tnesile strengths of different amalgams as produced by different mixers and trituration time are given in Figs. 3 and 4.

As can be learned from the tabulations above, these two proved important factors in their effect on the tensile strength. The tensile strength becomes large proportionally to the length of trituration but its increase tends to be slower in progression. With some, the maximum strength was registered, while with others a small increase was still measurable beyond 60 seconds trituration. The former trend was true of spherical amalgam, whereas the latter was of conventional amalgam. An increase in the compressive strength proportional to the trituration time[7–13] was also true of the tensile strength, as demonstrated in the present findings. CAUL et al. [12] who had studied five different amalgam alloys with S.S. White No. 3 mixer gave the trituration time of 20 to 80 seconds as optimal for obtaining the maximum compressive strength or an

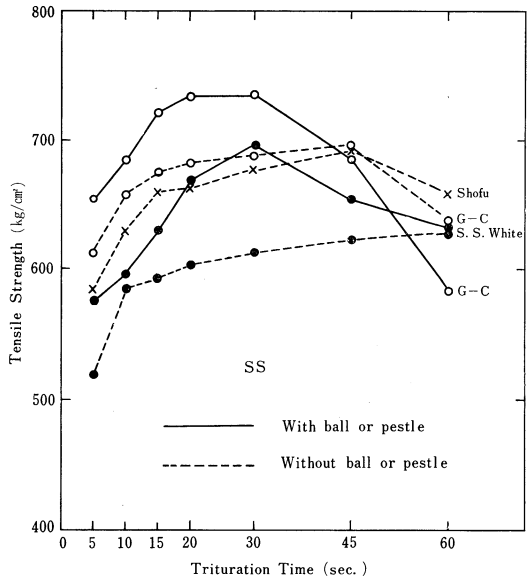

Fig. 3 Effects of Amalgamator and Trituration Time on Tensile Strength of Spherical Amalgam

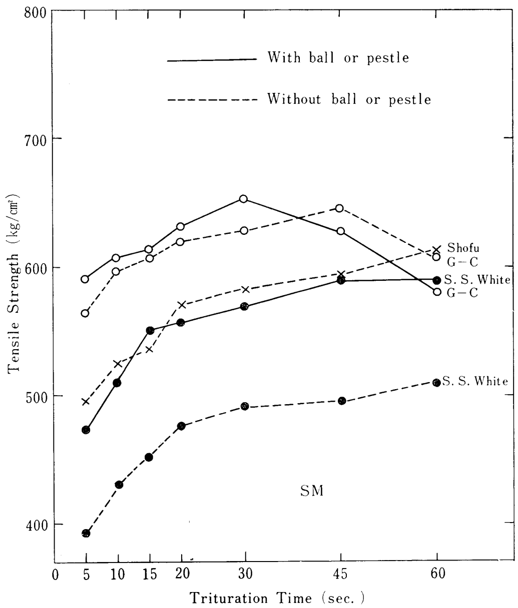

Fig. 4 Effects of Amalgamator and Trituration Time on Tensile Strength of Conventional Amalgam

approximation to it. HOLST[13], after a similar study on 8 different alloys, reported the trituration length of about 30 seconds as optimal in terms of the compressive strength. Our own findings, though differing somewhat from mixer to mixer and trituration time employed, indicated 15 to 45 seconds as an optimal trituration time; they are more or less in keeping with the above two sets of data. Although the mixer and trituration time as given in a manufacturer's are indicative of his recommendation for the supposely best clinical result, they are far from adequate in all cases. Some manufacturers' instructions are quite satisfactory but there are encountered others which are not specific enough as to a conjoint application of aiding device such as balls. Some instructions recommend as short a trituration as 3 to 5 seconds. In veiw of the fact that a small shrinkage is not clinically critical[14] and the new ADA specifications have adopted $0 \pm 20\mu/\text{cm}$, there is no need for an unnecessary reduction in the trituration time at the sacrifice of physicochemical properties of amalgam.

When different tensile strengths are comparatively examined at an optimal trituration time, a conjoint use of ball or pestle proves more effective. The degree of effectiveness, of course, varies from mixer to mixer or alloy in use. Of the mixers used, G-C Luna IIB (with ball) was found to attain to the maximum strength of 735Kg/cm^2 in 20 to 30 seconds. The capsule movement of a mixer is directly linked to the resultant tensile strength. The movement of S.S. White No. 3 mixer is found to be about 1/2 of other mixers under survey. The same trend is apparent in the presence or absence of a ball. When conventional amalgam is mixed by G-C Luna IIB (with ball) and Shofu Mixer (without ball) respectively, a definite difference is observable with the resultant

tensile strength. These findings suggest that trituration efficiency of amalgam is influenced not only by the presence of pestle or ball and capsule movement, but also by other factors such as dimensions of a pestle, trituration mechanism of a mixer, etc.

3.3 Number of mix increments.

The number of thrusts (80) and that of mix increments were compared with reference to the resultant tensile strength (Fig. 5). The strength was found to be more or less the same with more than 4 increments in spherical and more than 8 increments in conventional amalgam. When the number of thrusts was reduced, there took place a corresponding reduction in the tensile strength.

In actual clinical practice, triturated amalgam is transported into a prepared cavity in an adequate number of increments and thrusts are administered on it, repeating the procedure till an entire filling is completed. If amalgam is filled en masse without being divided in increments, that portion of amalgam which is in contact with the lower end of a cavity will not receive sufficient impact of thrust, thus resulting in an inadequate filling. However, research literature on the optimal number of thrusts is almost non-existent: it is chiefly resorted to empirical means.

The result of our test, in which filling was effected by means of a new "NON" condensing apparatus in a cavity 4mm in diameter and 8mm in height, established the number of 8 thrusts to be desirable in terms of resultant tensile strength.

3.4 Delayed condensation.

A glance at Fig. 6 convinces us that the length of time during which amalgam mix is exposed to air before condensation has direct bearings on resultant tensile strength.

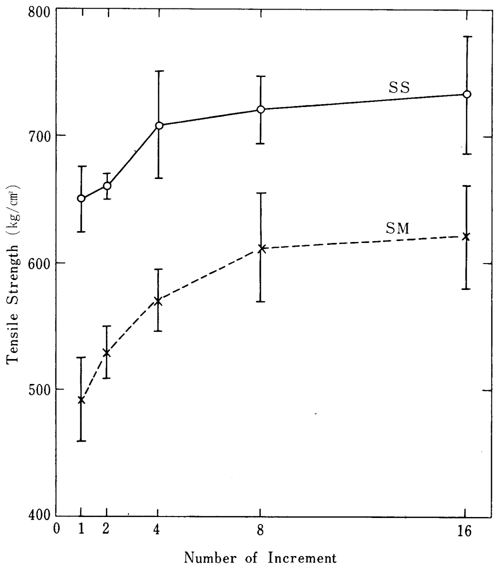

Fig. 5 Effect of Increment of Mix on Tensile Strength of Amalgam

The weakness of strength is partly explained that γ-1 and γ-2 phases already take place while amalgam is left exposed and the crystals become damaged at condensation[7]. In this connection, it has been pointed out by NAGAI et al.[16] that chemical reaction between mercury and alloy progresses while amalgam is left exposed and residual mercury becomes reduced, thus producing a higher viscosity of matrix afterward which will in turn make subsequent manipulation difficult. In his study of the compressive strength of amalgam, JØRGENSEN[17] gave per minute reduction of the strength to be 50Kg/cm^2. Our study with the focus on tensile strength here revealed per minute reduction of the strength to be 24Kg/cm^2 (condensed at a high pressure) and 32Kg/cm^2 (condensed at a low pressure) respectively.

It is maintained that, since the strength of amalgam becomes reduced propotionally to being exposed[17–19], amalgam mix left exposed longer than 3 to 3.5 minutes should be discarded and a new one prepared[7]. Here our own data indicate that after an exposure of 2 to 3 minutes the mix was found to be reduced in strength by nearly 90 % and 70 to 83 % after 5 minutes. Therefore we concur with SKINNER and others in maintaining that amalgam mix after 3 minutes should be substituted for a new one.

This needs to be borne in mind when there are more than one cavity to be filled: when the number and complexity of cavities so indicate, it is necessary that amalgam should be triturated as many times as called for, not triturating a whole mass at one time. At the same time, kinds of alloy, amount of mercury, condensation pressure, etc. should be given sufficient attention as they deserve.

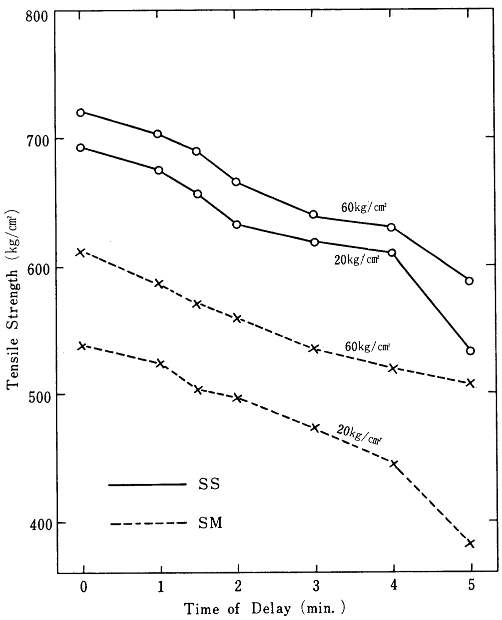

Fig. 6 Effect of Delageyd Condensation on Tensile Strength of Amalgam

3.5 Condensation time.

Our test data are given in Fig. 7. Condensation time is another important factor that influences resultant tensile strength, as a longer condensation time is attended with a corresponding reduction in the strength. An amount of pressure comes into play: a low pressure means a high reduction in the strength, as estbalished by per minute reduction of 20Kg/cm² (high pressure) and 34Kg/cm² (low pressure).

In our previous 3.4 experiment, the trituration time remained constant while the time before beginning filling was varied. Here the filling was begun immediately after the completion of trituration but different time lengths were adopted for effecting a filling. More or less the same data were obtained when amalgam mix was left exposed for 5 minutes and its filling effected in next 3 minutes, as in 3.4, and another which took 8 minutes including the trituration and filling, as in 3.5. Tensile strengths in the two cases: 71–83 % (former) and 63–84% (latter) were in keeping with each other. This may be explained that the longer time is necessitated by filling, the longer amalgam mix is left exposed. Therefore, it is important to be borne in mind that, though careful filling is a desirable thing, the elapse of time longer than is necessary should be kept at a minimum.

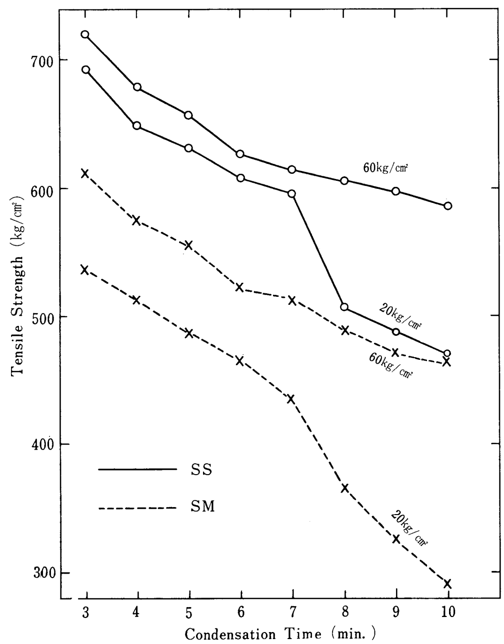

Fig. 7 Effect of Condensation Time on Tensile Strength of Amalgam

3.6 Condensation pressure and environmental temperature.

Fig. 8 gives our data under this heading. Whereas spherical amalgam is much less influenced by the difference in condensation pressure and its strength is hardly influ-

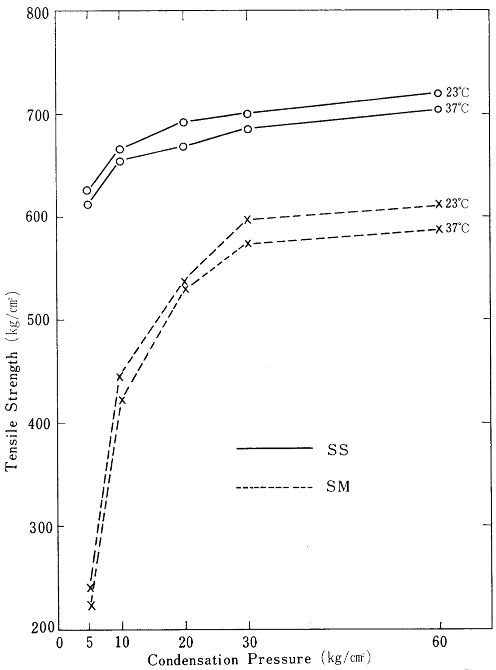

Fig. 8 Effects of Condensation Pressure and Stored Temperature on Tensile Strength of Amalgam

enced even by reduction in the pressure, conventional amalgam is easily susceptible to the difference in pressure. These facts can be also known from the previous data in 3.4 and 3.5.

Although somewhat lower strength is measured in water (37°C) than at room temperature of 23°C, the difference is by no means significant. When the tensile strength registered at a pressur of 60Kg/cm^2 is placed at 100, nearly 90 % of this strength is registered by spherical amalgam at 10Kg/cm^2 but, with conventional amalgam, this strength is lost by 70 % at the same pressure. The tensile strength of 625Kg/cm^2 obtainable for spherical amalgam at 5Kg/cm^2 requires some 12 times of the pressure or 60Kg/cm^2 for conventional amalgam. That spherical amalgam has a larger tensile strength than conventional amalgam at the same condensation pressure and this is particularly true of a small pressure, has been demonstrated not only by NAGAI et al.[7] but also confirmed by EDEN and WATERSTRAT[20] and KORAN and ASGAR[12].

Generally speaking, compressive strength of amalgam decreases proportionally to an increase in environmental temperature [12, 22]. The reduction in this strength from room temperature of 23°C to the oral temperature of 37°C is given to be 15 % by CAUL et al.[21] and 7% by JØRGENSEN[22].

Within the framework of the present study, the mean reduction in the tensile strength on the part of both amalgams is about 3 %, which is much smaller than the findings of these two investigators. It is our opinion that, within a range of 23 to 37°C, the tensile strength of amalgam is hardly influenced by temperature.

3.7 Mechanical condensation.

As given in Fig. 9, when spherical amalgam was packed at a pressure of over 200g and conventional amalgam at 500g by the use of a mechanical condenser, Auto Plugger, they attained to the same tensile strength respectively. As compared with a manual condensation, a mechanical condensation makes it possible to effect a satisfactory packing at a relatively low pressure. It is generally held that, done in a proper manipulative manner, there is no significant difference between manual and mechanical condensation in respect of the resultant strength[7, 9]. But mechanical condensation is attended with advantages such as a reduction in the condensation time because of uniform repetitive thrusts and a relatively low pressure[23]. As a matter of fact, many reports are in favor of mechanical condensation[18, 24, 25, 26].

A mechanical condenser, Auto Plugger, used in the present study was especially designed for packing spherical amalgam at a low pressure. With 100g pressure, this plugger brings forth the tensile strength of 556Kg/cm^2 in spherical amalgam, which corresponds to 563Kg/cm^2 of manual condensation. This kind of plugger can be also applicable to conventional amalgam which is packed at a relatively low pressure, too.

When a pressure load exceeds 1Kg, the tip of a plugger tends to go into spherical amalgam mix making condensation somewhat difficult. However, this derives from an excellent flow property of spherical amalgam[7] and, when this kind of plugger is used, there is no need for using a large pressure.

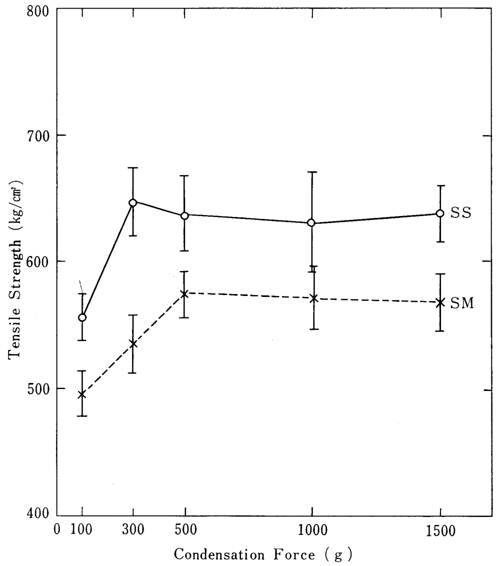

Fig. 9 Effect of Mechanical Condenser "Auto Plugger" on Tensile Strength of Amalgam.

4. Conclusions

The present study, which was directed to an elucidation of manipulative factors

concerned with the tensile strength, was conducted by an application of reliable diametral compression test. As a result, the authors arrived at the conclusions as follows.

1. A Hg-alloy ratio does not appreciably influence the tensile strength of amalgam.

2. The use of an effective mechanical condenser makes it possible to reduce time required for condensation and to obtain a large enough strength.

3. Strength of amalgam increases in proportion to the length of trituration and registers a maximum value at a certain time-point. The point at which the maximum length is reached or in its neighborhood is construed as indicative of an optimal trituration time.

Although differing from condenser to condenser, an optimal trituration time has a range of 15 to 45 seconds.

4. The conjoint use of ball or pestle with a capsule is attended with a better trituration result.

5. The more increments are used, the stronger will be tensile strength of amalgam. The result of various tests using different numbers of increments revealed that, with new "NON" condensing apparatus, 8 increments were satisfactory for a cavity of 4mm in diameter and 8mm in length.

6. Tensile strength of amalgam decreases proportionally to the time during which mix is left exposed to air before condensation. The amount of decrease is 24–32Kg/cm^2 per minute. In this respect, conventional amalgam registers more decrease than spherical amalgam.

7. Similarly, a longer condensation time results in the reduction of tensile strength. The amount of decrease is 20–34Kg/cm^2 per minute. Here again, conventional amalgam registers more decrease than spherical amalgam.

Therefore, it is important from a clinical point of view that minimum time should be spent from the end of trituration to the start of condensation.

8. Tensile strength of spherical amalgam is not appreciably influenced by a condensation pressure. conventional amalgam is more susceptible to an influence in this respect.

9. With a range of environmental temperature, 23–37°C, amalgam is hardly susceptible to a change in temperature.

10. Mechanical means of condensation is effective in preventing the reduction of tensile strength even at a low pressure. When spherical amalgam is used, there is no need for a high condensation pressure.

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