Studies on the Tensile Strength of Dental Amalgams by the Application of Diametral Compression Test

Part 1 Tensile Strength of Commercially Available Amalgam Alloys in Dental Use

by

Kazuo NAGAI, Masayoshi OHASHI,* Hiroyoshi HABU,**
Masahiro UEMURA, Fujio KORENAGA,* Naohisa GOTO,**
Yoshinari NAGATA and Yoshimasa FUJIMOTO**

Introduction

One of the great disadvantages of amalgam alloys as dental restorations lies in their fracture. This deficiency results from the mechanical properties of alloy itself, i.e., its tensile strength is much smaller than compressive strength.

TAYLOR[1] gave the tensile strength of amalgam alloy to be about one-tenth of compressive strength and RODRIGUEZ et DICKSON[2] and NAGAI et al.[3] gave it as 1/4–1/5 and 1/6.5 respectively.

In those studies previously undertaken, test specimens were made in the form of dumb-bells and for this reason, they tended to be broken by the chuck at a testing time resulting in a wide scattering of measurement data. This accounts for a relative paucity of research data on the tensile strength of amalgam alloy in the totality of a

---

*永井一夫, 大橋正敬, 土生博義, 植村正弘, 是永不二夫, 後藤尚久, 永田嘉成, 藤本善正:
Department of Dental Materials, Nihon Univ. School of Dentistry, Tokyo.
Received for publication; November 1969.

variety of researches published on different aspects of this clinically important dental restorative[4].

In 1943, AKAZAWA[5] devised a method by which it was possible to test a fragile material such as concrete, in the cylindrical specimens, for measuring its tensile strength both easily and accurately. The practicality of this method was subsequently tested out[6–11] and it is currently incorporated as part of standard concrete specification tests[12, 13].

APPLETON[14], in 1964, introduced this method into a dental field where it was applied to testing silicate cement and zinc phosphate. In the following year, BURNS and SWEENEY[15] applied it to dental amalgam and confirmed its reliability in enabling them to obtain the initial tensile strength of amalgam, eliminating the possibility of breaking down by the chuck and also the need for a grip.

Spherical amalgam alloy, a recent invention, has been studied from various angles and its excellent serviceability established[3, 16–27]. Of these published studies, the above new method was used by such workers as EDEN and WATERSTRAT[19], KORAN and ASGAR[20] and NAGAI, OHASHI et al.[26]. They are all agreed to the fact that spherical amalgam has a greater tensile strength than conventional lathe-cut amalgam even if it is condensed under a low pressure.

In the present study, the authors concerned themselves with a comparison of this new method with the old and examined the tensile strength of commercially available spherical alloy amalgam with that of conventional alloy amalgam comparatively.

Materials and Methods

2.1 Materials

By way of test materials, a selection was made of 5 spherical amalgam alloys and 5 conventional amalgam alloys (Table 1). For the comparative purpose of two testing methods, however, Shofu Spherical Alloy alone was used.

Table 1 Amalgam alloys tested

Code	Alloy	Batch No.	Alloy : Hg	Manufacturer
*SS	Shofu Spherical	69	1.0 : 0.85	Shofu Dental Mfg. Co., Japan
*TA	Toyo Atomized	54	1.0 : 0.85	Toyo Chemical Lab., Japan
*GA	G-C Atomic	C S 25	1.0 : 0.86	G-C Chemical Mfg. Co., Japan
*GAP	G-C Atomic Pellet	C G 3	1.0 : 0.9	G-C Chemical Mfg. Co., Japan
*KS	Kerr Spheraloy	0972M024	1.0 : 1.0	Kerr Mfg. Co., U.S.A.
+SM	Shofu Micro	43	1.0 : 1.0	Shofu Dental Mfg. Co., Japan
+GL	G-C Luna	R G 27	1.0 : 1.0	G-C Chemical Mfg. Co., Japan
+TN	Toyo No. 1	118	1.0 : 1.0	Toyo Chemical Lab., Japan
+SNT	S. S. White New True Dentalloy	1246607	1.0 : 1.0	S.S. White Dental Mfg. Co., U.S.A.
+DS	Degussa Standalloy	P 11.343	1.0 : 1.0	Degussa, W. Germany

*spherical alloy +conventional alloy

2.2 Preparation of test specimens

In triturating these amalgam specimens, the manufacturer's instructions were followed in the case of spherical alloys and a 1.0:1.0 alloy-to-mercury ratio was decided for conventional alloys. The mixes were triturated for 15 seconds by the use of G-C Luna IIB Amalgamator with a steel ball. The mixes then were packed by the New "NON" condensing apparatus for 3 minutes. A test specimen, in the cylindrical form of 4.0mm in diameter and 8.0 mm in length, was prepared at room temperature of 23 ± 2°C. For the comparison of new and old test methods, another specimen in the form of a dumb-bell previously used by NAGAI and OHASHI[3] was prepared: it was packed by a manual condenser with 2.5mm in diameter under a weight of 3Kg (approximately 60Kg/cm^2). Other specimens were also prepared in the identical manner by a manual condenser, so that they could be compared with those made by the New "NON" condensing apparatus in diametral compression test.

2.3 Methods

The diametral tensile strength of cylinder-shaped specimens was measured by the Autograph IS-10T (Shimadzu Instruments Co.), whereas dumbbell-shaped specimens were measured by the micro universal tester of the same manufacturer. The measurements were effected at a head speed of 1mm per minute. Except for those cases in which change in the tensile strength was measured on a consecutive basis, all other strength values were read at 24 hours. With commercial alloy products, change in their tensile strengths was consecutively measured as long as 90 days. Since the diametral compression test possesses a remarkable efficiency in measuring the initial strength of a brittle material[15], our concern was to measure the initial strength inside one hour, which was an impossibility with the previous method.

Tensile strengths from one to twenty-four hours after the trituration were also comparatively examined by changing condensation pressures applied. In all the tests, the arithmetic mean of 10 consecutive readings was taken as representing the strength of amalgams tested.

Results

3.1 Previous and new methods compared

Results of the old method using the dumbbell-shaped specimens and of the new method using the cylinder-shaped specimens are given in Table 2 and Fig. 1.

Table 2 Comparison of conventional and new diametral compression test

Test method Specimen form Condensation	Diametral Cylinder New "NON"	Diametral Cylinder Manual	Conventional Dumbbell Manual
Diameter of plugger (mm)	3.9	2.5	2.5
Tensile strength (Kg/cm^2)	721 (26)*	563 (95)*	505 (118)*
Residual mercury (%)	36.4	42.5	43.2

*Standard deviation

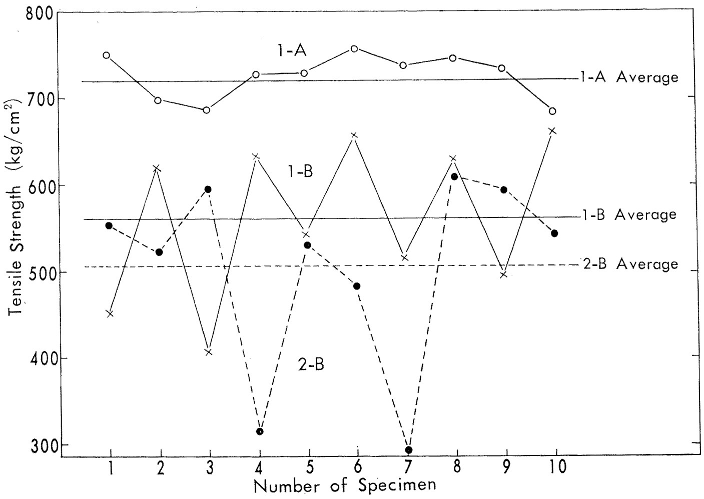

Fig. 1 Comparison of Conventional and Diametral Compression Test on Tensile Strength of Spherical Amalgam
1=Diametral compression test method
2=Conventional test method
A=New "NON" condensation
B=Manual condensation

When packed manually, the mean tensile strength under the old method is 505Kg/cm^2 and that by the new method is 563Kg/cm^2 with no marked difference between the two. On the other hand, those mechanically packed by the New "NON" condensing apparatus gave as much as 721Kg/cm^2 with little standard deviations.

3.2 Tensile strength of commercial amalgam alloys

Table 3 gives consecutive change in the tensile strength of spherical alloys from one to twenty-four hours under varying condensation pressures, while Table 4 gives the corresponding data for conventional amalgam alloys.

Comparative changes in different amalgam alloys under 60Kg/cm^2 are given in Fig. 2. Spherical amalgams SS, TA and KS give similar behaviors, while G-C products were inferior alike to other alloys: at 6-hour reading they were as low as 150Kg/cm^2 than others. Generally speaking, a tendency was observed that the tensile strength took on a rapid increase till 6 hours, after which the increase was both slow and a little.

Fig. 3 gives a comparison of tensile strengths after 24 hours packed under different pressures. There was no decrease in the tensile strength of spherical amalgam when a condensation pressure was lowered, while with conventional amalgam a decrease in a pressure was attended by a corresponding reduction in the tensile strength. An excellent spherical amalgam packed under a low pressure could well compare with conventional amalgam packed under a high pressure. One G-C spherical product studied, however, failed to have a larger tensile strength than conventional amalgam even packed under a high pressure.

Fig. 4 compares different tensile strengths at 6 hours, a most important time-point clinically. The tendency here was the same as that of 24 hours passage. Three G-C products gave the lowest values.

Table 3 Tensile strength of spherical amalgam alloys at 1–24 hours

Alloy	Condensation pressure	Specimen age (hour)				
		1	3	6	12	24
	Kg/cm²	Kg/cm²	Kg/cm²	Kg/cm²	Kg/cm²	Kg/cm²
SS	5	188 (16)	284 (17)	476 (46)	571 (35)	625 (36)
	10	229 (18)	310 (16)	539 (76)	621 (57)	667 (52)
	20	249 (9)	325 (25)	581 (48)	640 (66)	693 (22)
	30	247 (12)	361 (11)	647 (20)	677 (26)	701 (11)
	60	275 (7)	388 (23)	652 (59)	695 (47)	721 (26)
TA	5	177 (29)	218 (17)	408 (22)	505 (21)	533 (51)
	10	197 (35)	225 (22)	460 (26)	523 (36)	563 (59)
	20	219 (34)	260 (18)	525 (51)	558 (51)	585 (49)
	30	222 (12)	295 (42)	578 (33)	605 (29)	653 (15)
	60	236 (36)	358 (24)	595 (43)	650 (43)	707 (15)
GA	5	139 (14)	216 (34)	264 (25)	445 (15)	474 (13)
	10	162 (8)	233 (20)	302 (17)	491 (59)	504 (42)
	20	181 (8)	265 (14)	318 (33)	529 (11)	551 (76)
	30	185 (13)	273 (11)	414 (17)	537 (36)	555 (18)
	60	206 (5)	279 (16)	434 (41)	546 (37)	581 (30)
GAP	5	105 (17)	177 (21)	266 (19)	448 (17)	517 (10)
	10	129 (10)	235 (34)	296 (19)	490 (32)	583 (11)
	20	144 (10)	260 (18)	310 (22)	534 (30)	606 (12)
	30	166 (18)	267 (32)	399 (37)	548 (22)	642 (21)
	60	188 (21)	273 (28)	435 (24)	568 (40)	668 (24)
KS	5	106 (10)	275 (8)	490 (29)	544 (29)	588 (22)
	10	125 (10)	282 (6)	552 (29)	599 (21)	618 (36)
	20	146 (4)	303 (18)	576 (26)	618 (27)	662 (19)
	30	162 (8)	327 (15)	608 (15)	651 (15)	680 (23)
	60	184 (9)	447 (12)	622 (16)	662 (53)	700 (19)

Numbers in parentheses indicate standard deviation.

Table 4 Tensile strength of conventional amalgam alloys at 1–24 hours

Alloy	Condensation pressure	Specimen age (hour)				
		1	3	6	12	24
	Kg/cm^2	Kg/cm^2	Kg/cm^2	Kg/cm^2	Kg/cm^2	Kg/cm^2
SM	5	48 (2)	103 (17)	111 (18)	171 (18)	241 (52)
	10	82 (4)	187 (14)	326 (35)	393 (90)	445 (21)
	20	91 (3)	210 (5)	435 (31)	497 (48)	537 (15)
	30	98 (8)	247 (8)	504 (34)	571 (34)	598 (24)
	60	139 (8)	317 (7)	586 (21)	590 (35)	612 (43)
GL	5	49 (2)	84 (7)	149 (12)	194 (12)	263 (55)
	10	95 (14)	159 (4)	281 (50)	449 (55)	504 (38)
	20	98 (2)	187 (25)	387 (49)	471 (63)	533 (33)
	30	123 (20)	235 (15)	437 (49)	529 (22)	573 (14)
	60	198 (9)	356 (30)	466 (70)	578 (73)	579 (27)
TN	5	30 (1)	91 (12)	180 (10)	250 (20)	292 (23)
	10	64 (4)	149 (14)	245 (15)	505 (35)	572 (40)
	20	90 (5)	224 (23)	480 (30)	575 (39)	593 (20)
	30	112 (15)	286 (23)	555 (22)	603 (20)	633 (28)
	60	145 (16)	340 (31)	603 (23)	646 (12)	698 (26)
SNT	5	77 (1)	182 (12)	213 (3)	295 (27)	445 (20)
	10	90 (2)	194 (12)	243 (40)	400 (52)	548 (29)
	20	123 (7)	237 (14)	423 (21)	574 (18)	635 (13)
	30	133 (8)	307 (13)	497 (22)	605 (34)	637 (51)
	60	178 (14)	436 (33)	592 (20)	639 (32)	647 (12)
DS	5	79 (7)	177 (6)	290 (32)	482 (19)	543 (22)
	10	90 (2)	225 (13)	450 (14)	520 (45)	560 (17)
	20	113 (20)	385 (9)	515 (20)	602 (46)	639 (19)
	30	125 (5)	445 (45)	580 (38)	618 (28)	643 (8)
	60	208 (18)	491 (45)	601 (20)	632 (46)	667 (15)

Numbers in parentheses indicate standard deviation.

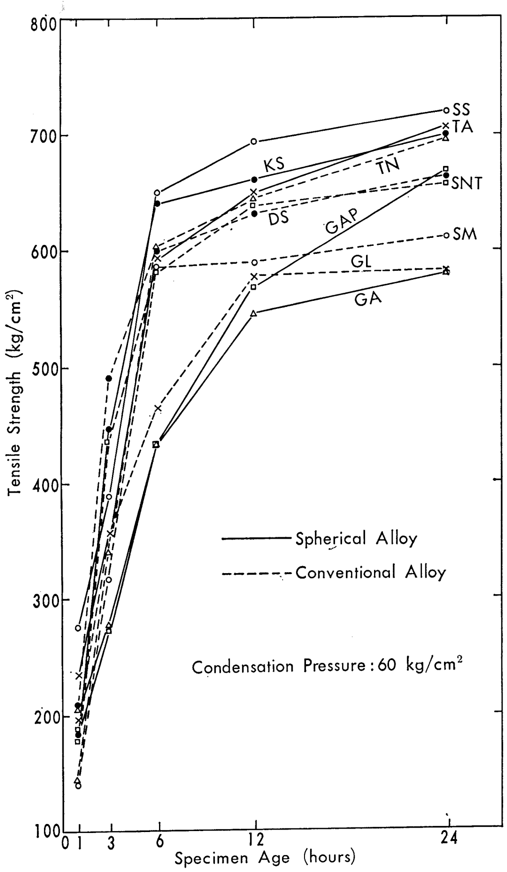

Fig. 2 Tensile Strength of 10 Commercial Alloys at Various Ages Ranging from 1 to 24 Hours

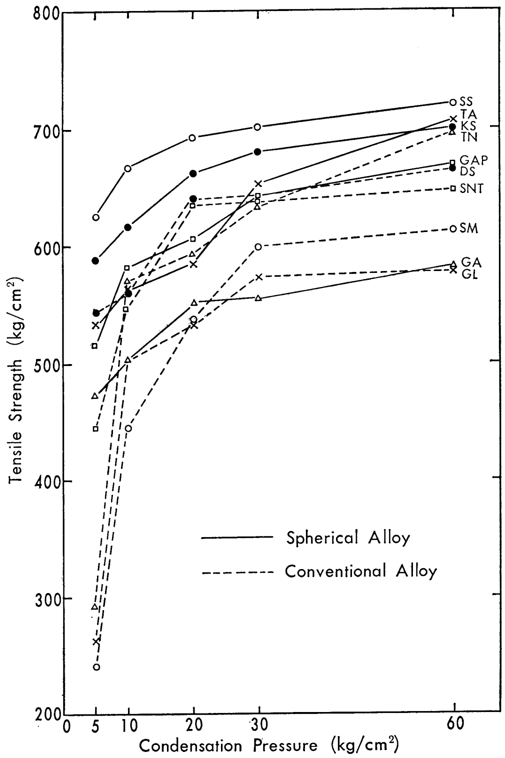

Fig. 3 Effect of Condensation Pressure on Tensile Strength of 10 Commercial Alloys at 24 Hours

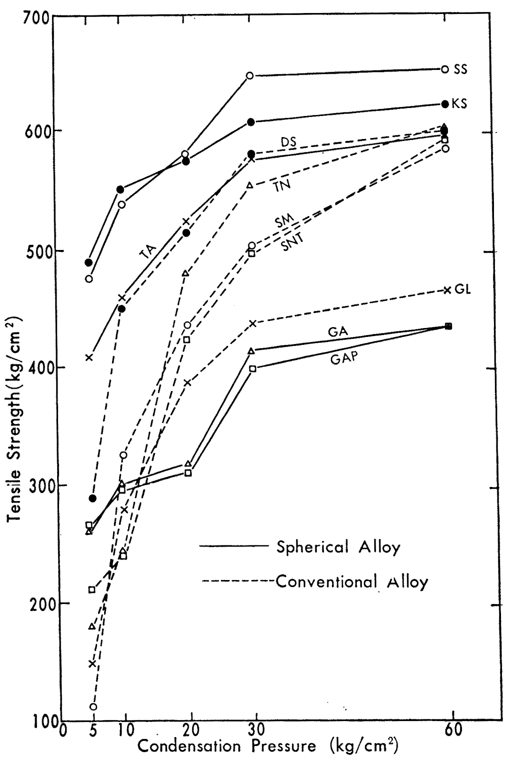

Fig. 4 Effect of Condensation Pressure on Tensile Strength of 10 Commerical Alloys at 6 Hours

Table 5 and Fig. 5 respectively give a 90-day consecutive mesurement of the tensile strengths: they increased till about 7th day, beyond which the increase was slow and a little. Of them, spherical amalgams SS, KS and TA gave more or less the similar strength while GA merely came up to the tensile strength of the lowerst group.

Tensile strengths within one hour were also measured (Table 6, Fig. 6). Both amalgam groups gave a straight-line increase till 30 minutes, the spherical group registering a higher reading generally with a single exception of KS. After 30 minutes, the average tensile strength of spherical amalgam was twice as large as that of conventional amalgam. Of them, KS behaved similarly as conventional amalgam till 30 minutes and then it increased in its tensile strength having the same tendency as SNT. SS continued its straight-line increase throughout 60 minutes.

Table 5 Tensile strengths of 10 commercial alloys at 1–90 days

Alloy		Specimen age (days)					
		1	3	7	14	30	90
		Kg/cm²	Kg/cm²	Kg/cm²	Kg/cm²	Kg/cm²	Kg/cm²
Spherical	SS	721 (26)	749 (20)	751 (70)	758 (49)	762 (15)	758 (103)
	TA	707 (15)	730 (90)	726 (42)	753 (26)	739 (68)	751 (17)
	GA	581 (30)	607 (86)	637 (70)	631 (19)	655 (38)	665 (62)
	GAP	668 (24)	676 (101)	701 (17)	711 (30)	718 (25)	720 (45)
	KS	700 (19)	725 (29)	735 (18)	737 (36)	748 (21)	752 (81)
Conventional	SM	612 (43)	623 (40)	625 (52)	642 (16)	645 (37)	654 (14)
	GL	579 (27)	603 (36)	615 (78)	606 (33)	628 (92)	634 (15)
	TN	698 (26)	696 (35)	704 (12)	696 (72)	709 (13)	710 (87)
	SNT	647 (12)	665 (25)	674 (83)	678 (12)	664 (75)	690 (13)
	DS	667 (15)	680 (25)	692 (18)	687 (96)	680 (14)	695 (80)

Numbers in parentheses indicate standard deviation.

Table 6 Early tensile strengths of 10 commercial alloys

Alloy		Specimen age (min.)			
		5	15	30	60
		Kg/cm²	Kg/cm²	Kg/cm²	Kg/cm²
Spherical	SS	13 (3)	57 (3)	129 (5)	275 (5)
	TA	16 (1)	63 (3)	154 (9)	236 (36)
	GA	19 (3)	71 (3)	147 (6)	206 (5)
	GAP	32 (2)	77 (3)	132 (7)	188 (21)
	KS	15 (3)	39 (4)	73 (6)	184 (9)
Conventional	SM	26 (2)	53 (7)	77 (2)	139 (8)
	GL	29 (2)	69 (10)	94 (10)	198 (9)
	TN	21 (2)	41 (2)	69 (3)	145 (16)
	SNT	14 (2)	39 (3)	76 (3)	178 (14)
	DS	22 (2)	47 (1)	80 (2)	208 (18)

Numbers in parentheses indicate standard deviation.

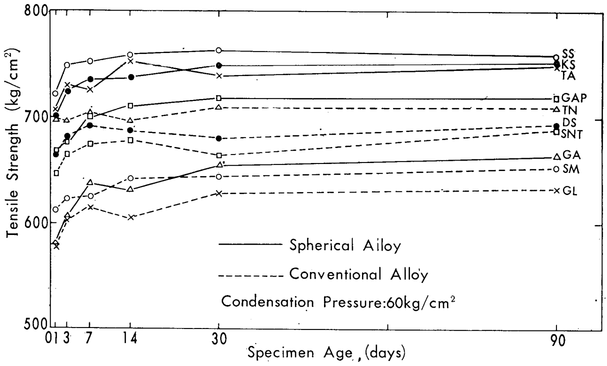

Fig. 5 Tensile Strength of 10 Commercial Alloys at Various Ages Ranging from 1 to 90 Days.

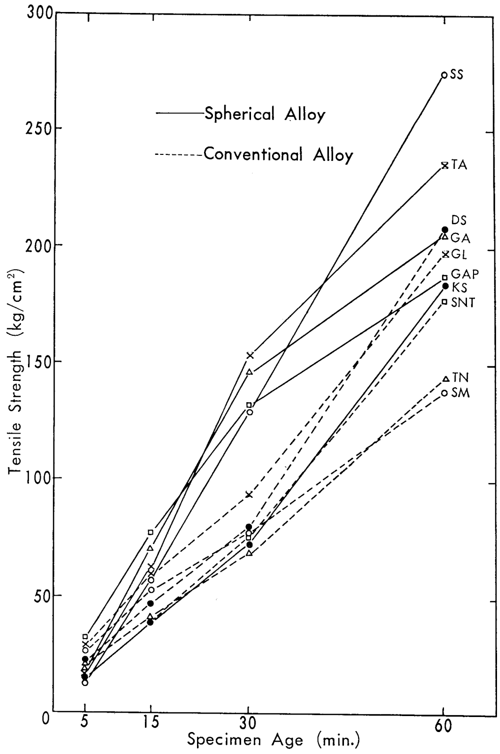

Fig. 6 Early Tensile Strength of 10 Commercial Alloys at 5~60 Minutes.

Discussion

4.1 Efficiency of previous and new methods compared.

We have been able to confirm a report of BURNS and SWEENEY[15] that diametral compression test is a reliable one. We have found that with this method one could prepare test specimens easily and accurately obtain the tensile strength of a fragile material with a minimum of data scatter.

With SS manually packed as an indicator, the previous method gave its tensile strength to be 505Kg/cm^2 and the new method 563Kg/cm^2 with no data scatter, there being no statistical significance between the two. The data are in keeping with 531Kg/cm^2 strength of spherical amalgam measured by NAGAI and OHASHI[3] by the old method.

When the tensile strength as packed manually was compared with that mechanically packed in the new method, we found that the latter gave as much as 28% increase. This value is again in keeping with 29% increase in the compressive strength measured similarly by the same investigators, NAGAI and OHASHI[23].

These findings confirm the fact that the new method gives far more exact measurements and that a mechanical condensing device (New "NON" condenser) is advantageous over a manual one.

4.2 Tensile strength of commercial amalgam alloys.

Although excellent properties of spherical amalgam as against conventional lathe-cut amalgam have been variously confirmed[16–27], it is pointed out by NAGAI and his associates[26] that these properties vary from spherical amalgam product to product with some being inferior to conventional amalgam products. In the present study, the same findings are true: while SS, KS and TA all give higher tensile strength than conventional amalgam some products definitely fail to come up to the strength expected. According to BURNS et al.[28], the tensile strength of amalgam after 15 minutes was 16–63Kg/cm^2 and that after 3 hours was 113–394Kg/cm^2, whereas our measurements were respectively 39–77Kg/cm^2 (mean: 56Kg/cm^2) and 273–491Kg/cm^2 (mean: 368Kg/cm^2). That our values are somewhat higher than those given by BURNS et al. is to be attributed to the difference in condensation pressures applied. The post 24-hour tensile strength of KS which was measured by KORAN and others[20] as 682Kg/cm^2 quite agreed with our measurement of 700Kg/cm^2 here.

After 24 hours, three excellent spherical amalgam products gave the tensile strength of 700–721Kg/cm^2 (mean: 709Kg/cm^2) while that of conventional amalgam was 579–698Kg/cm^2 (mean: 641Kg/cm^2). An increase in the tensile strength after 90 days exceeded only slightly that of 7 days and though some products registered a rapid increase in the initial strength, it was not true that they registered the highest value in the final measurement.

It is interesting to note from a clinical point of view that even if GA and GAP register a straight-line increase in their initial strength, within 30 minutes, they become much slower in speed than other alloys beyond this time point. An amalgam alloy having a faster setting can mean either a faster completion of condensation or its carving is possible at an early time. The fast setting amalgam has no meaningful relation to its initial strength after 3 to 6 hours.

Differences in an increase of the initial strength are accounted for by different reactive behaviors of alloy and mercury and possible factors include the material composition, particle distribution and difference in heat treatment from product to product. Table 7 give chronological change in the relative tensile strength of various amalgam products, where 7-day strength is taken as 100. Our findings endorse the statement of SKINNER[29] to the effect that though the compressive strength after 20 minutes is only 6% of what it will be after a week, it reaches 70 to 90% after 8 hours

and a slight increase is still observable after 6 months.

When one realizes that one factor for amalgam fracture is an occlusion before its complete setting, it becomes necessary to warn the patient not to chew hard on the restoration till about 6 hours when the tensile strength is 70 to 90% of what it will become after one week.

Three G-C products gave 62–76% strength after 6 hours and since these values are lower than those of other products, it follows that they have a higher possibility of fracture. In particular, GA and GAP can not be said to have usual properties expected of spherical amalgam.

Table 7 Relative tensile strengths of 10 commercial alloys

Alloy		Specimen age												
		Minutes			Hours					Days				
		5	15	30	1	3	6	12	24	3	7	14	30	90
		%	%	%	%	%	%	%	%	%	%	%	%	%
Spherical	SS	2	8	17	37	52	87	93	96	100	100	101	102	101
	TA	2	9	21	33	49	82	90	97	101	100	104	102	103
	GA	3	11	23	32	44	68	86	91	95	100	99	103	104
	GAP	5	11	19	27	39	62	81	95	96	100	101	102	103
	KS	2	5	10	25	61	85	90	95	99	100	100	102	102
Conventional	SM	4	9	12	22	50	94	94	98	100	100	103	103	105
	GL	5	11	15	32	58	76	94	94	98	100	99	102	103
	TN	3	6	10	21	48	86	92	99	99	100	99	101	101
	SNT	2	6	11	26	65	88	95	96	99	100	101	99	102
	DS	3	7	12	30	71	87	91	96	98	100	99	98	100

From this part of our discussion, it can be maintained that a clinically desirable amalgam should have not only a good final strength but a sufficient initial strength after 3 to 6 hours.

4.3 The relation of tensile strength to compressive strength.

The test specimens that were prepared under the identical conditions to those of tensile strength test were subjected to compressive strength test for comparative analysis. Table 8 gives a comparison between two strengths of SS and SM, while Fig. 7 deals with them chronologically. Fig. 8 is concerned with the condensation pressures applied.

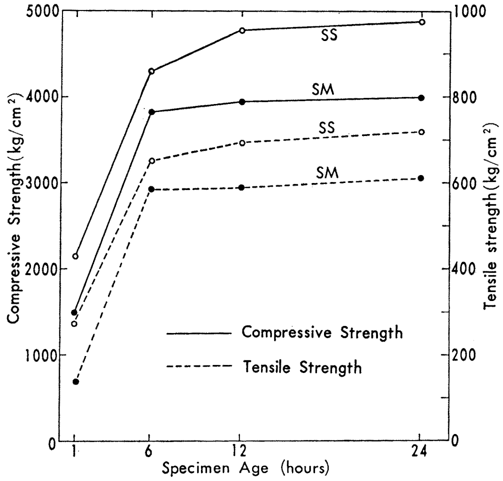

Fig. 7 Relation between Compressive Strength and Tensile Strength of Amalgam

As is known from these tabulations, both tensile and compressive strengths have similar tendencies with definite correlation (Fig. 9). Having a straight-line correlation, a ratio between the two strengths is 6.9 with SS and 7.5 with SM, no appreciable difference being noted between the two ratios. In previous studies, a ratio of compressive strength to tensile was given as 10 by TAYLOR[1], 4 to 5 by RODRIGUEZ and DICKSON[2] and 6.3 to 6.6 by NAGAI and OHASHI[3].

Table 8 Comparison of tensile and compressive strength of amalgam

Alloy	Strength	Specimen age (hours)				Condensation pressure (kg/cm^2)			
		1	6	12	24	5	10	30	60
SS	Tensile (kg/cm^2)	275	652	695	721	625	667	701	721
	Compressive (kg/cm^2)	2156	4300	4779	4867	4195	4463	4803	4867
	Compressive-tensile ratio	7.8	6.6	6.9	6.8	6.7	6.7	6.9	6.8
SM	Tensile (kg/cm^2)	139	586	590	612	241	445	598	612
	Compressive (kg/cm^2)	1491	3840	3894	3990	1981	3277	3771	3990
	Compressive-tensile ratio	10.7	6.6	6.6	6.5	8.2	8.0	6.3	6.5

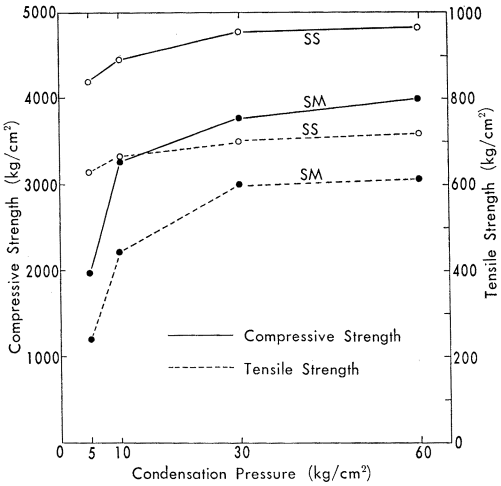

Fig. 8 Relation between Compressive Strength and Tensile Strength of Amalgam

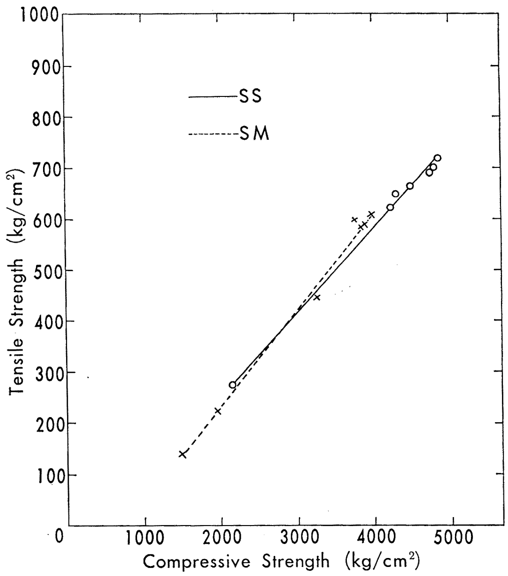

Fig. 9 Correlation between Compressive and Tensile Strength

Conclusion

As a result of our comparative study in measuring the tensile strength of commercial spherical and conventional amalgam alloys by the use of diametral compression test, we arrived at the conclusions as follows.

1. Diametral compression test is found to be quite easy in the preparation of test specimens with a minimum of data scatter. It can be recommended as a reliable test method of the tensile strength suitable for fragile materials.

2. The tensile strength varies from amalgam product to product. Some spherical products failed to come up to standards expected of spherical amalgam.

3. Percentile distribution of the average tensile strength with 7-day strength as 100 is as follows: 15 minutes (8%), 30 minutes (15%), one hour (29%), 6 hours (82%) and 24 hours (96%). An increase in the strength after 90 days was merely 2%.

4. Spherical amalgam gives a higher tensile strength than conventional amalgam. Its 24-hour strength is over 700Kg/cm^2.

5. Although the tensile strength of spherical amalgam is not affected by a condensation pressure to be applied, that of conventional amalgam will be reduced in proportion to a decrease in the pressure applied.

6. There exists a definite correlation between the compressive and tensile strengths. The ratio is 6.9 for spherical and 7.5 for conventional amalgam.

References

[1] Taylor, N. O.: A specification for dental amalgam alloys: A report to the Scientific Foundation and Research Commission of the American Dental Association, J. Amer. dent. Assoc., **17**: 112–124, (1930).

[2] Rodriquez, M. S. and Dickson, G.: Some tensile properties of amalgam, J. dent. Res., **41**: 840–852, (1961).

[3] Nagai, K. and Ohashi, M.: Studies on the tensile properties of spherical amalgam, J. Nihon Univ. Sch. Dent., **10**: 39–51, (1968).

[4] Mahler, D. B.: Analysis of stresses in a dental amalgam restoration, J. dent. Res., **37**: 516–523, (1958).

[5] Akazawa, Tsuneo: A new testing method to obtain the internal stress of concrete through compression, Part 1, J. Civil Eng. Soc., **29**: 777–789, (1943).

[6] Pelitter, R.: Theoretical investigation of Brazilian test, International Association of Testing and Research Laboratories, **17**: 15, (1954).

[7] Berenbaum, R. and Brodie, I.: Measurement of the tensile strength of brittle materials, Brit. J. Applied Physics, **10**: 281–287, (1959).

[8] Mitchell, N. B., Jr.,: The indirect tension test for concrete, Materials Research and Standards, **1**: 780–788, (1961).

[9] Lecrivain, L. and Lamberg, B.: Application of the Brazilian test to the study of ceramic products, L'Industrie Céramique, No. 534, 367–372, (1961).

[10] Rudnick, A., Hunter, A., and Holden, F. C.: An analysis of the diametral compression test, Materials Research and Standards, 283–289, April, (1963).

[11] Spriggs, R. M., Brissette, L. A. and Vasilos, T.: Tensile strengths of dense polycrystalline ceramics by the diametral-compression test, Materials Research and Standards, 218–220, May, (1964).

[12] Method of test for tensile strength of concrete, JIS A-1113, (1964).

[13] Standard method of test for splitting tensile strength of molded concrete cylinders, ASTM Designation: C 446-66, (1966).

[14] Appleton, J. H.: The effects of certain variables on strength and other properties of silicate and zinc phosphate cements, J. dent. Res. **43**: 913, Part 2, (1964, Abstract).

[15] Burns, C. and Sweeney, W. T.: Application of the diametral compression test to dental materials, Int. Assoc. dent. Res. program and abstracts, 122, (1965).

[16] Demaree, N. C. and Taylor, D. F.: Properties of dental amalgams made from spherical alloy particles, J. dent. Res. **41**: 890–906, (1962).

[17] WING, G. and RYGE, G.: Setting reactions of spherical-particle amalgams, J. dent. Res., **44**: 1325–1333, (1965).
[18] WING, G.: Spherical particle amalgams, Austral. dent. J., **11**: 265–273, (1966).
[19] EDEN, G. T. and WATERSTRAT, R. M.: Effect of packing pressures on the properties of spherical alloy amalgams, J. Amer. dent. Assoc., **74**: 1024–1029, (1967).
[20] KORAN, A. and ASGAR, K.: A comparison of dental amalgams made from a spherical alloy and from a Comminuted Alloy, J. Amer. dent. Assoc., **75**: 912–917, (1967).
[21] NAGAI, K., OHASHI, M. and MIYATSU, H.: Studies on spherical amalgam alloy in the light of dental technology, J. Nihon Univ. Sch. Dent., **8**: 149–185, (1966).
[22] NAGAI, K. and OHASHI, M.: Studies on the dimensional change of dental amalgams, with reference to the dimensional change of spherical amalgam developed in Japan, J. Nihon Univ. Sch. Dent., **9**: 1–19, (1967).
[23] NAGAI, K. and OHASHI, M.: Three studies on a newly developed spherical amalgam in Japan and suggestions for its specification, J. Nihon Univ. Sch. Dent., **9**: 43–48, (1967).
[24] NAGAI, K. OHASHI, M. and HASEGAWA, K.: Comparative study on the marginal strengths of conventional and spherical amalgam alloys, J. Nihon Univ. Sch. Dent., **9**: 49–66, (1967).
[25] NAGAI, K. and OHASHI, M.: Study on the corrosion resistance of spherical amalgam with reference to the human saliva, J. Nihon Univ. Sch. Dent., **9**: 143–163, (1967).
[26] NAGAI, K. and OHASHI, M. and HABU, H.: Some physical properties of spherical amalgams for commercial use in the world, J. Nihon Univ. Sch. Dent., **10**: 1–18, (1968).
[27] PLUMP, E. H.: Spherical alloy amalgam; A clinical study, presented at the Int. Assoc. dent. Res. annual meeting for 1967.
[28] BURNS, C. L., SWEENEY, W. T. and CAUL, H. J.: Amalgam by early tensile strength, Int. Assoc. dent. Res. program and abstracts, 90, (1967).
[29] SKINNER, E. W. and PHILLIPS, R. W.: The science of dental materials, W. B. Saunders Company, Philadelphia, 5th ed., (1960).