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THE INFLUENCE OF TEMPERATURE ON THE CRUSHING STRENGTH OF DENTAL AMALGAMS

by

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INTRODUCTION

It is well known that one of the most frequent causes of failure of amalgam fillings is the high incidence of marginal fracture. Every dental practitioner studying his patients' amalgam fillings will no doubt have noticed how fillings which looked quite satisfactory when inserted, gradually become more and more defective at the marginal areas, and how secondary caries develops and spreads from the defects. Several authors (*Mertensmeier* 1956, *Fischer & Mertensmeier* 1957, *Nadal et al.* 1961) have studied fractured amalgam margins. Apart from the last-mentioned work, which showed a reduction in the incidence of fracture with increased crushing strength of the amalgam, this problem has not been investigated in detail.

The present work was designed to examine to what degree the crushing strength of amalgam is influenced by various forms of heating.

In the oral cavity, amalgam fillings are exposed to temperature changes, chiefly during the final polishing and during the intake of hot and cold foods. From investigations by *Souder & Peters* (1920) and others, it is well known that silver amalgams begin to melt (release drops of mercury with dissolved alloy compo-

nents) at a temperature of 70—80°C. It is also well known that even light polishing can raise the surface temperature of amalgam so much that it begins melting, and that, in general, the crushing strength of a material declines gradually with rising temperature until it is reduced nearly to zero as the melting point (the solidus temperature) is reached. In this connection it must be pointed out that it is possible to chew food which has a considerably higher temperature than the oral cavity, and that relatively thin amalgam margins will, quite rapidly, be heated to approach the temperautre of food entering the latter.

1. Crushing strength of amalgam at different temperatures

Methods

In preparing the amalgam specimens from the various alloys, filing and mercury were proportioned as recommended by the manufacturers and mixed in a Wig-L-Bug mechanical amalgamator for so many seconds that a plastic homogeneous mass was obtained. The entire mass was transferred to a steel cylinder, 5 mm in cavity diameter, where it was condensed for 3 minutes. Condensation was started 1 minute after trituration was completed and was effected by an upper and lower piston. A constant pressure of either 15.6 or 30.0 kg was used in the various experiments. After removal from the steel mold, the amalgam specimens were stored at room temperature (22 ± 2°C) for 72 hours and then crushed in a Losenhausen 1000 kg testing machine with a loading rate of 5 kg per sec. The specimens were 10 ± 1 mm in length.

One minute before the load was applied the specimens were placed in ethylene glycol preheated to testing temperature ± 1°C. To avoid appreciable cooling from the compression plates of the tester, two glass plates, 6 mm thick, were heated to test temperature and placed under and on top, respectively, of the specimen.

The tests were made on nine different silver amalgams and two copper amalgams; the copper amalgams were heated for 10 minutes at 150°C before mixing. One silver amalgam (No. 2 in Table 2) was examined for crushing strength at different tem-

peratures up to 90°C, while the remaining products were tested only at room temperature and at 60°C. In the first case ten specimens were used for each temperature. In the experiments including all the alloys only five specimens were tested for each combination of variables, except in the case of copper amalgams where the number was increased to ten owing to the scattering of the values. The mean value and the standard deviation were computed for each combination of brand and temperature. The experimental results are shown in Tables 1 and 2 and in Figure 1.

Results

Table 1

Crushing strength (kg/cm²) at different temperatures for alloy No. 2. Condensation pressure 15.6 kg (0.78 kg/mm²).

Temperatures, C°	24	37	50	60	70	80	90
Crushing strength	3206	2973	2621	2277	1800	1150	480
Standard deviation	81	82	100	65	32	45	28
Reduction %	0	7	18	29	44	74	85

Table 2

Crushing strength (kg/cm²) of various amalgams at room temperature and at 60° C.

Condensation pressure 30 kg (1.5 kg/mm²).

Alloy	1	2	3	4	5	6	7	8	9	10	11
Room temperature	3536	3701	3195	3557	3381	2944	2966	3324	2708	2583	2283
Standard deviation	76	30	158	72	60	102	105	55	107	468	221
60° C	2801	2827	2443	2607	2584	2292	2296	2558	2225	2201	2733
Standard deviation	76	51	92	80	42	93	116	22	40	476	313
Reduction %	21	24	23	27	24	22	23	23	18	15	—20

It is evident from the data presented in Tables 1 and 2 and in Fig. 1 that temperature has an essential influence on the crushing strength of silver amalgams. Heating from room temperature to 60° reduced the strength by about 25 %, and it is probably a safe assumption that the loss of strength generally will be about 20 %

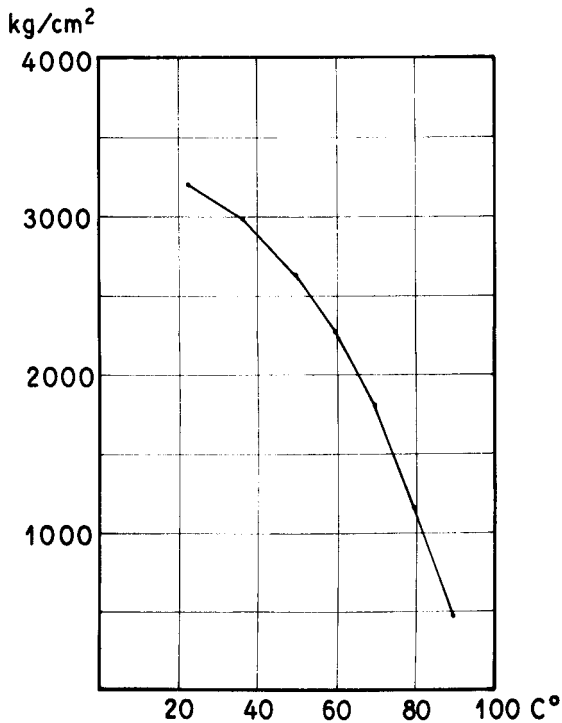

Fig. 1. Crushing strength of product No. 2 at elevated temperatures.

by heating from mouth temperature to 60°. The increasing steepness of the curve in Figure 1 indicates that temperature rises above 60° will reduce the strength at an even higher rate. The two copper amalgams (Nos. 10 and 11) behaved somewhat differently from the silver amalgams, especially so Brand 11, which had higher crushing strength at 60° than at room temperature.

II. Crushing strength of amalgam after heating and recooling

Methods

The test specimens in these experiments were made in the same way as previously; they were condensed under two different pressures, 5 or 15.6 kg. Ten specimens were used for each combination of variables. Seventy-two hours after preparation each specimen was heated separately by one minute's storage in ethylene glycol preheated to the desired temperature. After recooling to room temperature for 1—2 minutes, the specimens were measured for crushing strength. Only one alloy was tested, viz. No. 2 in Table 2. The results are shown in Table 3 and Figure 2.

Table 3

Crushing strength (kg/cm²) of silver amalgam after short heating and recooling to room temperature.

Temperatures, C°	23	50	60	70	80	90	100	120	150
Condensing pressure 15.6 kg (0.78 kg/mm²)	3674*	3356	3327	3096	2904	874	545	521	439
Standard deviation	121	134	82	180	135	115	20	44	29
Reduction %	0	9	9	16	21	76	85	86	88
Condensing pressure 5 kg (0.25 kg/mm²)	2853	2719	2642	2483	1951	901	334	281	—
Standard deviation	185	113	86	171	125	33	15	39	—
Reduction %	0	5	7	13	32	68	88	90	—

* This strength value is somewhat higher than the corresponding value of 3206±81 kg/cm² in Table 1. The cause is undoubtedly the different compression plates used.

Further, the ability of amalgam to regenerate its mechanical properties after heat treatment as described was tested on a series of specimens, which after 1 minute's heating to 80°, 100°, or 120°C were stored for different times and subsequently crushed. As a control of these experiments the same amalgam was examined for rate of hardening as expressed by its crushing strength at different times after trituration. For each combination of vari-

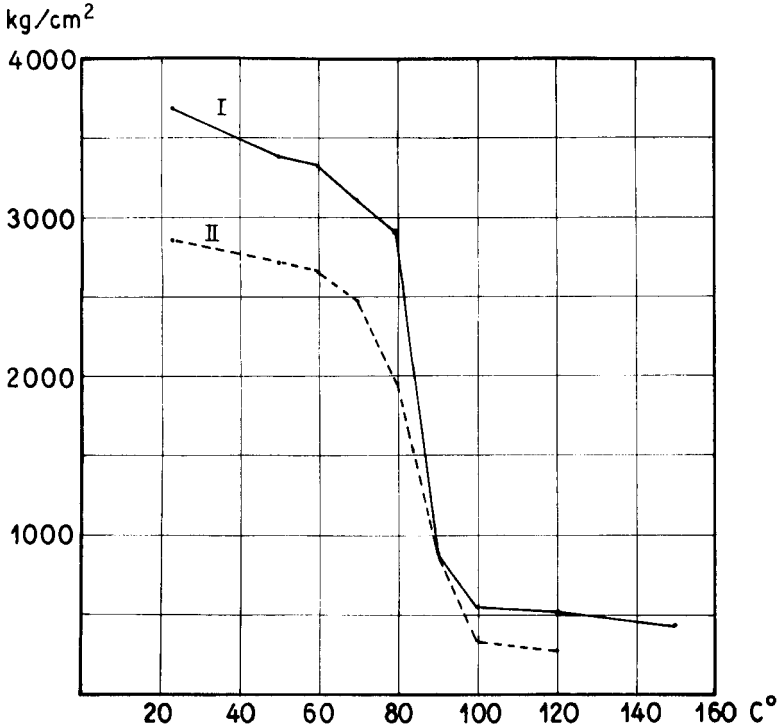

Fig. 2. Crushing strength of product No. 2 after one minute's heating to different temperatures and recooling to room temperature. I, condensation pressure used in preparation of the amalgam specimens, 0.78 kg/mm² II, condensation pressure, 0.25 kg/mm².

ables five specimens were used, apart from the first measurement of crushing strength immediately after the heating, and all measurements after 72 hours or more, where ten specimens were used for each combination. The results are presented in Table 4 and Figure 3.

Finally it was examined how much the length of heating time affected the crushing strength immediately after recooling to room temperature. The method was as described above; the specimens were heated for 30, 60, or 120 seconds. Only alloy No. 2 was used, and 10 specimens were crushed for each heating time. The results were as follows: 30 sec., 2971 ± 155 kg/cm²; 60 sec., 2904 ± 135 kg/cm²; 120 sec., 2455 ± 140 kg/cm².

Table 4

Crushing strength of silver amalgam at different times (hours) after short heat treatment.

Temperatures, C°	0	1	2	4	8	24	48	72	720
80°	2904	3210	3337	3463	3535	3779	3658	3603	
Standard deviation	135	109	85	42	43	34	66	102	
100°	545	2180	2619	2939	3263	3592	3662	3665	3687
Standard deviation	20	103	95	81	134	140	154	184	223
120°	521	2037	2145	2380	2649	3097	3397	3541	
Standard deviation	44	53	20	134	57	84	175	106	
Control	—	852	1246	2041	2704	3505	3643	3674	3847
Standard deviation	—	28	107	89	140	138	106	121	144

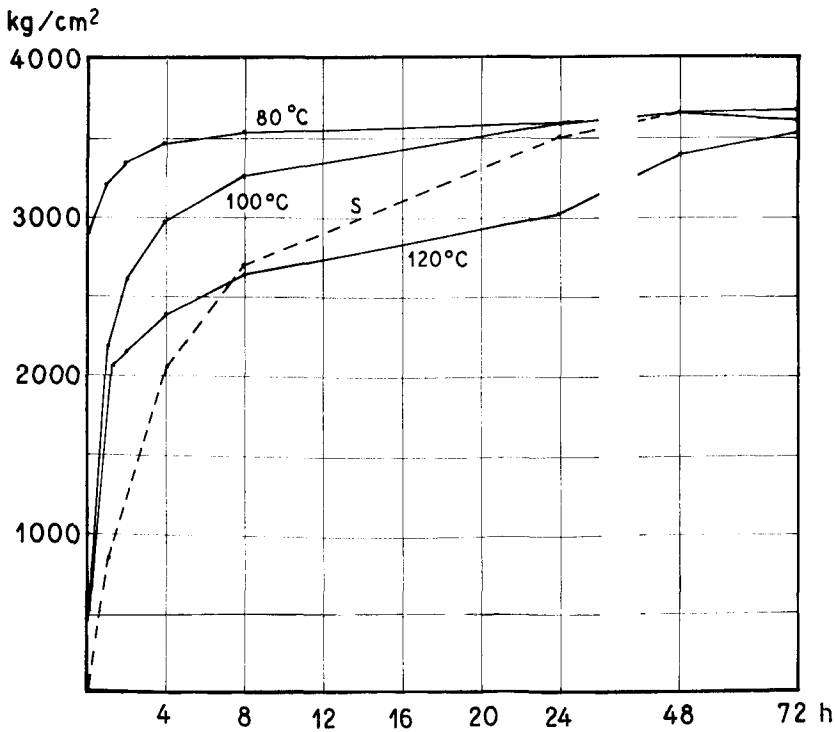

Fig. 3. Crushing strength of product No. 2 at different times after one minute's heating and recooling to room temperature. The numbers at the curves indicate the temperatures to which the specimens were heated; s, the setting curve, which indicates the crushing strength at various times after preparation of the specimens.

RESULTS

This group of experiments demonstrates that short heating of hardened silver amalgam can weaken it very considerably and the more so, the higher the temperature is elevated. Silver amalgam weakened by short heating regains its original strength within a relatively short time. The lower the temperature rise the shorter the time of regeneration.

DISCUSSION

The present investigation shows that in terms of crushing strength the dental amalgams are very sensitive to variations in temperature, and that a risk of marginal fracture is materially increased by heating of amalgam fillings brought about as described in the introduction.

In practice it is possible to carry out polishing of fillings with caution so that the temperature rise will be moderate. Cautious polishing has scarcely any decisive influence on the duration of the margins, partly because the initial strength of the amalgam is restored rather fast, partly because experience shows that very few amalgam margins do fracture during the first hours or days after polishing.

The combined action of heat and pressure during mastication is a factor which cannot be controlled in practice. With the exception of copper amalgam all dental amalgams used in this investigation weakened to about the same degree when heated to 60°. Such an increase in temperature must be considered within the limits of physiological possibility. This shows that prevention of marginal fracture of amalgam fillings as a result of weakening by temperature rises is practicable only by promoting such general factors which increase the mechanical resistance of the amalgam margins. These factors will be dealt with in a later article on marginal fracture of amalgam fillings.

SUMMARY

Investigations were made on the influence of temperature upon the crushing strength of amalgams, partly at elevated temperatures (Tables 1 and 2, Figure 1), partly after short heating and

recooling to room temperature (Table 3, Figure 2). Furthermore it was investigated how fast short-heated and recooled amalgam will recover strength (Table 4, Figure 3).

The experiments show that the strength is essentially reduced by increased temperature, and that the amalgam specimens regain their mechanical properties after a relatively short time.

Addendum

After this manuscript was completed, a study was published in the Journal of the American Dental Association (*67:* 670—678, 1963) by *H. J. Caul and co-workers,* entitled, "Effect of rate of loading, time of trituration and test temperature on compressive strength values of dental amalgam". Using five different alloys the authors found a similar, though somewhat larger reduction of the crushing strength at raised temperatures than reported in the present work.

RÉSUMÉ

INFLUENCE DE LA TEMPÉRATURE SUR LA RÉSISTANCE À L'ÉCRASEMENT DES AMALGAMES DENTAIRES

Des recherches ont été faites sur l'influence de la température sur la résistance à l'écrasement d'amalgames, d'une part lorsqu'on élève la température (Tableau 1 et 2, Figure 1), d'autre part après un chauffage de courte durée suivi d'un refroidissement à la température de la pièce (Tableau 3, Figure 2). Les auteurs ont de plus étudié la rapidité avec laquelle l'amalgame ayant subi un chauffage de courte durée suivi d'un refroidissement recouvrent sa résistance (Tableau 4, Figure 3).

Les expériences montrent que la résistance est en premier lieu réduite par l'élévation de la température, et que les éprouvettes d'amalgame recouvrent leurs propriétés mécaniques après un temps relativement court.

ZUSAMMENFASSUNG

DIE BEDEUTUNG DER TEMPERATUR FÜR DIE DRUCKFESTIGKEIT DENTALER AMALGAME

Es wurde eine Untersuchung angestellt über die Bedeutung der Temperatur für die Druckfestigkeit von Amalgamen, teils bei erhöhten Temperaturen (Tabellen 1 und 2, Abb. 1), teils nach kurzer Erwärmung und Wiederabkühlung (Tabelle 3, Abb. 2). Ferner wurde untersucht, wie schnell kurzzeitig erwärmtes und wiederabgekühltes Amalgam seine Festigkeit wiedererlangt (Tabelle 4, Abb. 3).

Die Untersuchung zeigt, dass die Festigkeit des Amalgams sich beim Erwärmen auf die bei den Versuchen benutzten Temperaturen erheblich vermindert, dass aber die Festigkeit nach verhältnismässig kurzer Zeit wiederhergestellt wird.

Der Temperaturfaktor an sich lässt sich kaum in der Praxis ändern, nur wo es sich um das Polieren von Füllungen handelt; es ist jedoch zweifelhaft, ob die Polierungstemperatur für die Haltbarkeit der Füllungen von wesentlicher Bedeutung ist.

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