J Forensic Sci, Jul. 1978, Vol. 23, No. 3

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Identification of Suitable Plaster for Crime-Scene Casting

Over the years police literature has generally recommended plaster of Paris [*1*] or dental plaster [*2*] to make casts at crime scenes. Even extremely unsophisticated testing indicates that different types of plaster vary considerably in tensile strength, hardness, and setting times under similar environmental conditions. Test studies indicate that plaster of Paris and dental plaster are the least suitable materials for police use because they are the least resistant to breakage and abrasion [*3*].

Other police literature also recommends a variety of commercial preparations, some of which are stated to be better than others, but further product identification and comparative testing is not given [*4-6*]. United States Gypsum Co. alone produces 21 plasters which bear such names as Ultracal, Ultracal 30, Hydrocal B-11, Tuf Art Hydrocal, White Art Plaster, Industrial Molding Plaster, Duracal, and Hydrostone Super X. These products are purchased by dental-formulating laboratories (a prime source of casting plaster for police work), which compound new mixes and distribute them under new brand names such as R. & R. Castone, Duroc, Kerr Snow White Plasters, Vel Mix, and Super Die. Other types of outlets may also alter, repackage, and rename plasters, increasing the difficulty of identifying a commonly available plaster of known and suitable characteristics.

Because of the mixed references to types of plaster in police literature, and the many recommendations to use the unsuitable plaster of Paris and dental plaster, it is necessary to present some background data on plaster. It is also essential to conduct comparative tests under simulated environmental conditions to decide which plaster would be most suitable for police casting work.

Background on Plaster

Plaster is made from a natural mineral known as gypsum [*3*]. The gypsum is either gray or white unless coloring materials are added. The coloring process is not standardized, and therefore the color changes from time to time. Gypsum is processed in two ways to produce two basic types of plaster. The first process produces a soft plaster called beta-hemihydrate, the principal constituent of dental plaster. This type is made by heating pulverized gypsum until three fourths of its chemically combined water is removed and

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army, of the Air Force, or of Defense. Received for publication 24 March 1977; revised manuscript received 7 Dec. 1977; accepted for publication 12 Dec. 1977.

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then cooling the dehydrated gypsum. Stronger plaster, called alpha-hemihydrate, is made by the second process, which requires placing small chunks of gypsum in vessels, pressurizing the vessels, heating the gypsum to drive off the water, cooling, and then pulverizing the dehydrated mineral. Casts made of plaster produced by the second process are four to five times as strong as those made with plaster produced by the first process.

The most widely available product made from the stronger alpha-hemihydrate is dental stone, frequently referred to in the plural, as "dental stones," because it is subdivided into two classes based on particle size: Class I and Class II stones. Class I stones are termed dental stones and Class II, die stones. Die stones are up to 30% stronger and correspondingly harder.

The cost of casting materials available to police varies from 42¢/kg (18¢/lb) for a 23-kg (50-lb) sack of Duracal, a mixture of plaster and cement, to $20.79/kg ($9.00/lb) for the cheapest silicon casting rubber. Casting plasters all cost less than $1.16/kg (50¢/lb). Dental plaster retails around 92¢/kg (40¢/lb). The most expensive plaster tested during this evaluation was Castone, at $1.02/kg (44¢/lb) in a 11-kg (25-lb) container. These prices are retail, for the smallest amounts available, excluding shipping costs.

The accuracy of plasters used to make casts of shoe and tire impressions should be judged by the plaster's percentage of expansion and ability to reproduce detail. All plasters expand when they set, from a maximum of 0.3% for dental forms of plaster to a maximum of 3% for wall-patching plasters. Only two of the plasters tested during this evaluation are used for dental purposes, but all were within the 0.3% limit for dental materials. Knowledge of this characteristic of plaster is needed to explain discrepancies in landmark locations on casts that are compared with suspect footwear and tires.

All dental plasters must be able to reproduce line details down to 0.05 mm in width under low-angle illumination, without magnification, 30 min after a premixed quantity of plaster is added, in accordance with specifications established by the American Dental Association. Of the tested materials Duracal is the only product not manufactured to this specification. It is intended as a quick patch construction material that does not require the resolving power of dental materials. However, the resolving power of any plaster exceeds that of most materials containing a shoe or tire impression. Because of this fact, no examination was made of the resolving powers possessed by the plasters tested in this evaluation.

Several accelerator and retarder chemicals are added to plasters by source manufacturers and formulators. These, as well as even small amounts of chemicals deliberately or accidentally added by police users, can affect plaster. Tests on plaster of Paris with 41 organic and inorganic compounds in concentrations of 0.25% of the plaster by weight altered the usual setting time of 30 min to as short as 10 min and as long as 12 h. When the concentration was raised to 2%, the time ranged from 3 min to 48 days [7].

The tensile strength of plaster of Paris also varied widely (from 12 to 130% of the control specimen), but not in proportion to the setting time. For example, the addition of 2% cane sugar, commonly recommended in police literature to increase setting time, increased a 30-min setting time by only 3 min but increased the tensile strength more than 25%.

Chemicals, such as sodium chloride, are mentioned in police literature for use in varying plaster-setting time, but recommended quantities are inexact and variable, and comparative test results are not presented.

Although police literature most often recommends sodium chloride as an accelerant to setting time for plaster, use of even a 5 to 10% solution can reduce the strength of the cast by 50%. Calcium chloride also weakens casts but is three times more effective in preventing freezing. Since less calcium chloride than sodium chloride is needed, a lower freezing point is possible with a relatively greater strength of the cast than if sodium chloride is used.[3]

[3]C. B. Roe, development engineer, Tooling and Casting Div., U.S. Gypsum Co., personal communication, 1974.

During the time that the tests presented in this paper were being conducted with calcium chloride, two important items concerning chemical additives were found in Skinner and Phillips' *The Science of Dental Materials* [3]. The first item is that varying the concentration of some chemicals can reverse their effects. For example, 2% of a chemical may accelerate plaster-setting time, 5 to 20% may retard it, and more than 20% may again accelerate it. Therefore, it is important to insure that proper concentrations of chemicals are used.

The second item concerns potassium sulfate. It is identified as the most potent accelerator of setting time known for plasters and allegedly produces no variable effects at any concentration. Tests with a 2% concentration produced an accelerated setting time for plaster of Paris at room temperature almost equal to the setting time produced by sodium chloride but with a tensile strength increase of 25%, as compared to a 30% decrease with sodium chloride. Unfortunately, this information was obtained too late to be applied to the present tests.

Incidental additives of this type can be introduced from water sources or soil. For example, Special Agent Barry Hennessey of the U.S. Air Force Office of Special Investigations relates that, despite many attempts to make plaster casts of soil impressions in Libya on the Mediterranean Sea, he and other agents were unable to make the plaster harden. The bonding of silicates to plaster is another problem presented by soil, which is why sand is more difficult to remove from casts than clay or humus. Problems such as these illustrate that plaster casting is not a simple process, as it might appear at first glance. In fact, "In spite of the fact that gypsum has been used by itself or in the form of one of its derivatives such as plaster for many centuries, there are many gaps in the knowledge of its chemistry" [3].

Methods

Tests were conducted to study setting times for plaster and resistance of the casts to abrasion with various temperatures, altitudes, and soils. Five plasters were selected for testing (Table 1).

R. & R. Castone, like some other dental stones, is yellow. It is available from the Reynolds and Ransom Co., a dental-products formulator.

Vel Mix, a die stone, was selected because die stones are reported to be harder and stronger than dental stone. A product harder than dental stone might also be more durable under crime-scene conditions. It is beige or pale lavender and available from the Kerr Manufacturing Co., another dental-products formulator.

TABLE 1—*Mixtures of plaster and distilled water used to prepare test casts.*[a]

Generic Name	Trade Name and Source	Plaster, g	Water, ml
Dental stone	R. & R. Castone; Randolph and Ransom Co.	102.51	32.16
Die stone	Vel Mix; Kerr Manufacturing Co.	100.00	30.00
Alpha-hemihydrate (AHH)	Hydrocal White; U.S. Gypsum Co.	86.60	36.50
AHH and cement	Duracal; U.S. Gypsum Co.	105.23	32.00
AHH with dimensional control	Ultracal 30; U.S. Gypsum Co.	94.35	33.54

[a]Casts were made in 464-ml (16-oz) translucent polyethylene cups with flat bottoms 76 mm (3 in.) in diameter and slightly slanted sides.

Hydrocal White, a type of plaster used by dental formulators to produce dental stone, consists primarily of alpha-hemihydrate. It was selected to determine whether a significant difference exists between the dental stone and its precursor. It is white and produced by the U.S. Gypsum Co.

Duracal was selected because it was identified as the most waterproof, water-erosion-resistant plaster produced by the U.S. Gypsum Co. Once set, it appeared to be highly resistant to the process used to clean crime-scene casts. It is about the color of cement.

Ultracal 30 was selected because it is identified as one of the U.S. Gypsum Co. plasters having the best dimensional control. It is a light-gray plaster.

Molds for the casts were 464-ml (16 oz) translucent polyethylene specimen cups with flat, 76-mm (3-in.) diameter bottoms and slightly slanted sides. The amount of plaster needed to make about a 12-mm (½-in.) layer was calculated based on a "Gypsum Cement and Plaster Volume and Mix Calculator," on other information provided by U.S. Gypsum Co., and trade material accompanying plaster containers. Some adjustment was needed in most cases because the recommended ratio of plaster to water for maximum strength was difficult to pour, making it unusable for making most crime-scene impressions. The amounts of plaster and water used in our tests are presented in Table 1.

Distilled water was used for mixing. The plaster was placed in the container, the water added to it, and the mixture immediately stirred about 30 strokes for 20 s with a wooden tongue depressor.

The setting time was determined by using a #2 pencil in the following manner. When the mixed plaster appeared to be setting, the surface was repeatedly marked with the pencil until a good black mark was obtained without gouging the surface. Scratch resistance was determined by scrubbing the bottom surface of each cast 25 times in one direction with a wet used toothbrush, the stiffest one locally available.

Two altitudes were selected for the tests, ground level (79 m or 260 ft above sea level) and 3 km (10 000 ft). These altitudes appear to represent likely extremes in the field. Tests at different altitudes were included because no indication of the effects of altitude appears in police literature. The tests were conducted in the hypobaric chamber located at the Armed Forces Institute of Pathology.

Since the temperatures at crime scenes vary widely, casts at such scenes may also vary to some degree. Three environmental temperatures were selected as most likely representing average and extreme field conditions. These were −18, 22 (room temperature), and 49°C (0, 72, and 120°F). Subsequently, additional cold tests were made at −4°C (25°F) because casts did not set in 2 h at −18°C (0°F). For this reason an additional low-temperature test was also devised, with a 5% calcium chloride solution based on dry plaster weight, to accelerate both setting time and prevent freezing. Cold testing was done in a small freezer and tests at 49°C (120°F) were done in a small Thelco incubator oven. Temperature varied ±1.6°C (±3°F) during testing at the various temperatures.

Additional tests were then made over wet soils having a pH of 2.2 to 8.8. The complexity and variety of soil chemistry, with effects such as those in Libya, indicate that the soil-plaster interface may require specialized study, so the use of varied pH is considered to be merely a point of departure. Wet soil was used in the tests with the expectation that any adverse chemical reaction would be most severe with wet soil. In addition, impressions at crime scenes that are likely to retain detail should be those in moist soil.

Six millimetres (¼ in.) of dry soil was placed on the bottom of a polyethylene container and 15 ml distilled water added to the top. The plaster preparation was similar to that in tests in neutral molds except that it was mixed in another polyethylene container and poured onto the soil.

Setting time was again judged by marking the upper surface with a #2 pencil. The casts were tested for abrasion by scrubbing them 25 times with the used toothbrush after first removing any loose soil.

Results

While altitude had no appreciable effect on the setting time of the tested plasters, temperature changes did (Table 2). R. & R. Castone (dental stone) and Vel Mix (die stone) produced the best results of the five plasters tested. Castone had the shortest setting time while still providing an adequate working period. Vel Mix had a slightly longer setting time and also tended to produce more undesirable lumps when mixed.

Altitude did not produce a noticeable difference in setting times or resistance to abrasion (Table 3) in any of the plasters. The higher temperatures reduced setting times but not to a detrimental level, and resistance to abrasion was not affected except for the increased speed with which casts became resistant. Resistance to abrasion was unaffected by altitude but high temperatures decreased the time between setting and when no further abrasion took place.

Colder temperatures produced major problems with all five plasters. In the −18°C (0°F) tests with water as the solvent, all plaster appeared to freeze, resulting in ice crystals on all surfaces of casts. The freezing time was about 30 min, which was less than the setting time for some plasters at higher temperatures. The Castone and Vel Mix casts

TABLE 2—*Setting times, in minutes, of five plasters at various environmental conditions.* [a]

Generic Name	49°C (120°F) Ground	49°C (120°F) Altitude	22°C (72°F) Ground	22°C (72°F) Altitude	−18 and −4°C (0 and 25°F) Ground and Altitude
Dental stone	10/10	9/10	13/14	12/13	hardened in 30-88 min[b]
Die stone	26/27	26/28	36/36	34/38	hardened in 58-70 min[b]
Alpha-hemihydrate (AHH)	49/52	47/59	69/72	59/74	hardened in 28-150 min[c]
AHH and cement	32/34	35/36	55/59	67/68	hardened in 28-150 min[c]
AHH with dimensional control	22/22	22/22	35/37	34/37	hardened in 28-150 min[c]

[a]Times for duplicate samples are reported in each category. Altitude represents a simulated altitude of 3 km (10 000 ft).

[b]Retained shape when returned to room temperature.

[c]Several never hardened completely, appeared to freeze at −18°C (0°F), and lost shape when returned to room temperature; judged unsatisfactory for field use.

TABLE 3—*Resistance to abrasion of five plasters which set under various environmental conditions.* [a]

Generic Name	49°C (120°F) Ground	49°C (120°F) Altitude	22°C (72°F) Ground	22°C (72°F) Altitude	−18 and −4°C (0 and 25°F) Ground and Altitude
Dental stone	5	5	5	5	5 at −4°C (25°F)[b]
Die stone	5	5	5	5	continuous[b]
Alpha-hemihydrate (AHH)	15	15	15	45	continuous[c]
AHH and cement	30	30	90	90	continuous[c]
AHH with dimensional control	15	15	15	15	continuous[c]

[a]Test times in minutes from set time when no further abrasion occurred; simulated altitude of 3 km (10 000 ft).

[b]Moderate to severe abrasion for more than 8 h.

[c]Failed to set properly, lost shape upon return to room temperature, and had to be discarded as unusable for field conditions.

retained their shape when allowed to warm to room temperature, indicating that their normally fast setting times allowed them to set at least partially before freezing.

The use of a 5% calcium chloride solution eliminated surface crystals that can distort fine detail on the surface of a cast and prevented the plasters from freezing. This process allowed some plasters to set, but at two to six times the room temperature set time. Some such tests were terminated after several hours because the plaster appeared to have set only partially, as indicated by thickening or general and spotty crusting. A setting time of even an hour was considered unsatisfactory for use at crime scenes where time constraints are frequently severe.

An additional effect of calcium chloride was a softening of the final product. Mixtures that set or froze and mixtures that failed to solidify, whatever the reason, were subsequently allowed to warm to room temperature before being tested for abrasion. Abrasion of these was moderate to severe even after several weeks, indicating that a lengthy curing process does not increase abrasive resistance.

The results of tests conducted at −4°C (25°F) were basically the same as at −18°C (0°F), except for Castone, which set the quickest, did not have surface crystallization, and showed no abrasion after being warmed to room temperature. The next best plaster, Vel Mix, still produced surface crystals but was more resistant to abrasion than Castone in the −18°C (0°F) tests. With Vel Mix, too, the addition of calcium chloride removed the surface crystallization but also reduced the resistance to abrasion. In addition, the Vel Mix setting time at this temperature was almost twice that of Castone.

The test results in neutral molds indicated that R. & R. Castone (dental stone) is more likely to set under varied conditions, in the shortest time, and with adequate resistance to abrasion. Tests were then run with Castone upon wet soil. Table 4 illustrates the setting time of two soils with the highest and lowest pH as a typical result. Resistance to abrasion was the same: no abrasion within 5 min of setting at 22 and 49°C (72 and 120°F), and none at −4°C (25°F) when tests were conducted after the casts reached room temperature. Contact with soils having varied pH does not appear to affect the plaster setting time of R. & R. Castone.

Conclusions

The most commonly recommended casting plasters for police work—dental plaster and plaster of Paris—are inferior to other commonly available plasters. Of the five plasters tested, dental stone performed the best and far better than previously recommended police products. Although at −4°C (25°F) dental stone did not perform as well as probably desired by most users, it still surpassed the results of plasters previously used at crime scenes. The setting time at −4°C (25°F) was 30 to 88 min verses 12 to 14 minutes at 22°C (72°F) and 9 to 10 min at 49°C (120°F).

The suggestion, frequently seen in police literature, that table salt can be used to hasten setting time at colder temperatures is not recommended because it severely reduced the strength of the plaster casts. Likewise, calcium chloride, a recommended alternative, is not recommended. Dental literature indicates that potassium sulfate may be the best accelerant at cold temperatures, but it was not tested in this study. Its use may further enhance the use of dental stone at cooler temperatures.

Although chemicals in different soils can be expected to affect the quality of plaster casts, tests using soils with pH from 2.2 to 8.2 produced no variation in the gross characteristics or setting times of casts made with dental stone. Tests at altitudes of 79 m and 3 km (260 and 10 000 ft) produced no variation in setting time for dental stone or gross characteristics of resulting casts.

Tests of resistance to abrasion of the dental stone indicate that at 22°C (72°F) and above a used toothbrush of the stiffest available type will produce no noticeable abrasion

TABLE 4—*Setting times, in minutes, of dental stone while in contact with soils of different pH.*[a]

	49°C (120°F)		22°C (72°F)		−4°C (25°F)	
Soil pH	Ground	Altitude	Ground	Altitude	Ground	Altitude
2.2	10/10	9/9	11/12	13/13	49/61	53/70
8.8	10/11	9/9	11/12	12/12	54/65	53/58

[a]Times for duplicate samples are reported in each category; simulated altitude of 3 km (10 000 ft).

of a cast 10 min after it sets. At temperatures of −4°C (25°F) no abrasion will result if the cast is allowed to warm to room temperature before being scrubbed with the toothbrush. Extra care should be taken in cleaning casts made at temperatures below −4°C (25°F) because moderate to severe abrasion can be expected from the same type of toothbrush.

Summary

Tests of five casting plasters were made in polyethylene cups to determine the effects of temperature and altitude on the setting time and subsequent resistance of set plaster to abrasion. Dental stone, the plaster that set under the widest range of temperature and maintained a satisfactory resistance to abrasion, was then retested in contact with soils of various pH. Contact with the soils produced no apparent effect. The need for such tests under varied conditions duplicating some of the conditions found at crime scenes was based on the vagueness of police literature about casting plaster and its application to recording crime-scene footwear and tire impressions.

Acknowledgments

Thanks are due LTC Robert R. McMeekin, MC, USA, chief, Division of Aerospace Pathology, for his considerable time, efforts, and patience in connection with procedures, test, equipment formats, and suggested sources of additional information.

Almost all of the test casts were prepared by MSGT Robert G. Howell, TSGT Robert A. House, and SSGT John H. Besselman, Jr., all members of the USAF.

Considerable information on application and marketing background was provided by Mr. C. B. Roe, development engineer, U.S. Gypsum Co., Chicago, Ill. The time he spent answering questions in writing and by telephone, as well as providing technical reports and sources of other information, is greatly appreciated.

Soil specimens used in tests on soil were supplied by U.S. Department of Agriculture state soil scientists from Utah, New Mexico, and Florida, as well as by Dr. John Foss, Department of Agronomy, University of Maryland. Dr. Foss and R. Fred Miller, also of that Department, provided essential background on soil chemistry.

Mr. Louis Millikin and Mr. Hal Waters, Safety Research Laboratory, National Highway Traffic Safety Administration, also provided assistance regarding tests, equipment, and suggested sources of information.

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