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TECHNICAL NOTE

GENERAL; CRIMINALISTICS

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A New Method for Casting Three-Dimensional Shoeprints and Tire Marks with Dental Stone

ABSTRACT: Dental stone is used as the major material for recovering three-dimensional shoeprints and tire tracks from crime scenes. The procedure for using dental stone sparsely changed over the years. There are two common methods for mixing dental stone: (i) a premeasured amount of dental stone is put in a zip-lock bag to which water is added, and (ii) the water and dental stone are mixed in a bucket. We suggest a novel rapid and efficient method of mixing dental stone and water in a bottle. These methods were compared at equal conditions. The parameters measured were the number of air bubbles, the strength of the cast, the ease of use, and the sharpness and quality of the accidental characteristics present in the cast. The proposed bottle method has the advantages of both the bucket and the zip-lock methods hence it combines strength, sharpness, high quality, and ease of use.

KEYWORDS: forensic science, shoeprints, three-dimensional shoeprints, plaster cast, dental stone, casting procedure

Footwear and tire impressions have proven to be important type of evidence in many crime scenes (1). Casting footwear and tire impressions has been used for forensic purposes since 1854, when Hugoulin first used plaster of Paris as a casting material for shoeprints (2).

Both plaster and dental stone, which are the most common casting products for forensic uses (3), are gypsum products (calcium sulfate dihydrate—$CaSO_4*2H_2O$) used for dental purposes as well. Dental stone (calcium sulfate hemihydrate—$CaSO_4*\ ½H_2O$) is actually plaster that went through a heating stage during the initial manufacturing process.

Heating gypsum to a high temperature (110–130°C) causes loss of three-quarters of the water during crystallization to form calcium sulfate hemihydrate ($CaSO_4*\ ½H_2O$):

$$\underset{\text{Gypsum (plaster)}}{CaSO_4 * 2H_2O} \xrightarrow{110-130^{\circ}C} \underset{\text{Plaster or stone (Dental stone)}}{CaSO_4 * ½H_2O + 1½H_2O_{(g)}}$$

Mixing water with hemihydrate gypsum obtains a product which is stronger and harder than the product of gypsum because of a different crystal arrangement. The ratio of the water to the hemihydrate powder is an important factor in determining the physical and chemical properties of the final gypsum product. The higher the W:P (water:powder) ratio, the longer the setting time and the weaker is the gypsum product (4).

These variations explain the need to follow the manufacturer W:P recommendations when using the powder.

For casting three-dimensional prints, two main techniques for mixing the dental stone with water are usually applied:

- Using a bucket to stir a premeasured amount of dental stone added to a premeasured amount of water.
- A premeasured amount of dental stone is kept in a zip-lock bag and a premeasured amount of water is added later.

Though the gypsum industry states that the ideal mixing procedure involves the addition of the powder to the water to produce a homogenous slurry (4), the zip-lock method is widespread because of the simplicity of its use, storage, and no need for cleaning after use. Unfortunately, with this method, the quality of the casts varies because of the difficulty in determining when the powder particles are completely soaked with water, and therefore, occasionally, the cast impression is of poor quality (3).

This article presents a method for mixing the dental stone and the water in a rapid and efficient way. This method—"the bottle method"—has the simplicity of the zip-lock method and yet produces higher-quality cast impressions.

Methods

To compare the bottle method to the traditional "zip-lock" and bucket methods, we used a brand new shoe and made several cuts on different locations of the shoe sole surface (Fig. 1*a*). The cuts varied in size and shape (Fig. 1*b*). The shoeprints were imprinted in Biofoam® (Smithers Bio-Medical Systems, Kent, OH), commercially available foam that deforms under minimal pressure to conform to the shape of the object deforming it. This material preserves the finest details in the examined shoeprints (5). One set of prints was made in very fine clay soil that preserves the small minutiae in the print as well. The cast on soil was prepared as a control, to see if the Biofoam® preserves the fine details of the shoeprint similarly to fine grain soil.

All the casts were made with 1000 g of dental stone (Glastone, Dentsply Limited, Addelstone, U.K.). The volume of water added and the mixing time varied. The initial and greatest volume of water was 500 mL, which is higher than the manufacturer's

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recommendation (6). This was the volume of water recommended in the instructions for the evidence technicians in Israel and was set in the past as a method for making the plaster casts more fluid and easier to pour. Bodziak and Hammer (3) recommend adding a little more water (0.5 oz which is approximately 15 mL) to the plaster than recommended, but using 500 mL of water for 1 kg of plaster instead of 220 mL recommended by the manufacturer, is pushing their recommendation a bit to far.

The smallest volume of water used was according to the manufacturer's recommendations for dental purposes, 220 mL per 1 kg plaster.

Thermometers imbedded in straws were placed in all the dental stone casts, reaching the bottom of the dental stone mixture (Fig. 2). The temperature was recorded every few minutes.

Three mixing methods were applied: For the "reclosable bag—zip-lock" method, 500 mL of water was added to the dental stone in a "zip-lock" bag. The casting material was then mixed by massaging and kneading the bag for 1 min until the water and the dental stone seemed completely mixed, and no lumps were observed.

For the "bucket" method, 500 mL of water was poured into a bucket. The dental stone was added to the water and then allowed to settle and soak for 2 min. The mixture was then stirred thoroughly for 4 min (5).

For the "bottle" method, the first set of experiments was performed with 500 mL of water that was added to the dental stone in a 1.5 L bottle. The closed bottle was vigorously shaken for 40 sec.

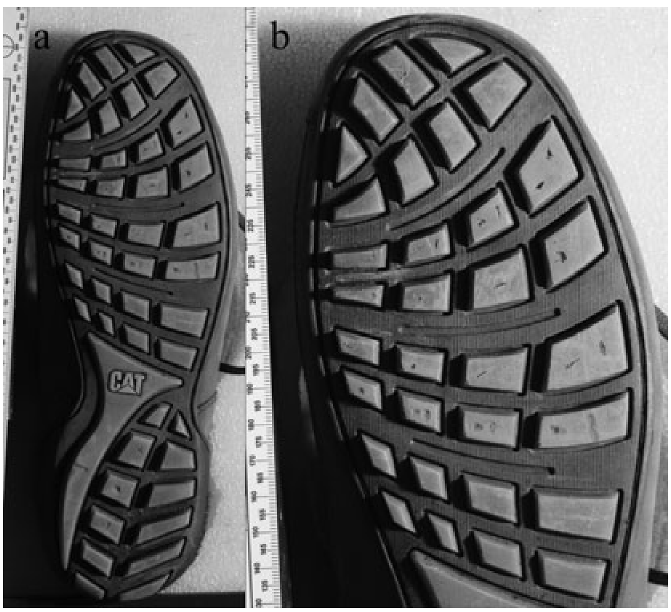

FIG. 1—*(a) The shoe sole used for the experiment. (b) Focus on the cuts on the shoe sole.*

FIG. 2—*The experiments array—the thermometer is placed in one dental stone cast.*

Different conditions were then tested: the dental stone was added to the water to "soak" it in the water and not vice versa. The time for shaking the mixture varied from 40 sec to 5 min. The volume of water was another parameter checked and varied from 210 to 500 mL.

The temperature of each cast was measured during the drying process. A probe was placed in a straw affixed in the cast, to measure the temperature near the base of the cast. The temperature was measured every few minutes until room temperature was reached.

Several parameters were measured to determine the quality of the resulting casts:

- The casts were examined by shoeprint experts. Comparisons were made between the casts made by the three methods and the test impression, with special attention to the clarity and quality of the individual characteristics.
- Air bubbles were counted on the elements of the sole pattern using a magnifying glass.
- After complete drying of the casts, their durability to friction was examined by rubbing the back of the cast with a finger and observing the amount of powder removed.

Results

The Biofoam® has proven to be a good substrate for performing the experiments, because none of the tested parameters differed from the natural fine clay soil substrate we examined.

The air bubbles that remained in the casts with all mixing methods were normally very small, tenths of a millimeter. We divided the bubbles into two categories, smaller than 0.5 mm and larger than 0.5 mm as shown in Fig. 3. Surprisingly, the number of air bubbles on casts produced with the reclosable bag method was significantly higher than on those produced by the two other methods. Casts produced by the bottle method had no more air bubbles than casts produced by the bucket method (Fig. 4).

The temperature variation during the drying process showed a similar pattern throughout all of the experiments. Figure 5 shows that the initial dental stone mixture loses heat once it is poured into the shoeprint. The temperature then rises up to a maximum point and gradually cools down back to room temperature. There was no difference in the drying duration for the three casting methods, but the amount of water in the cast had a major effect on this process.

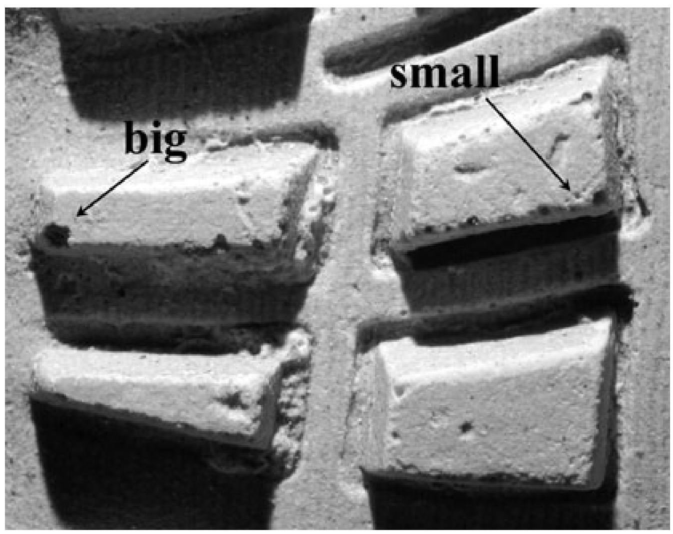

FIG. 3—*Large and small air bubbles on a casted shoeprint.*

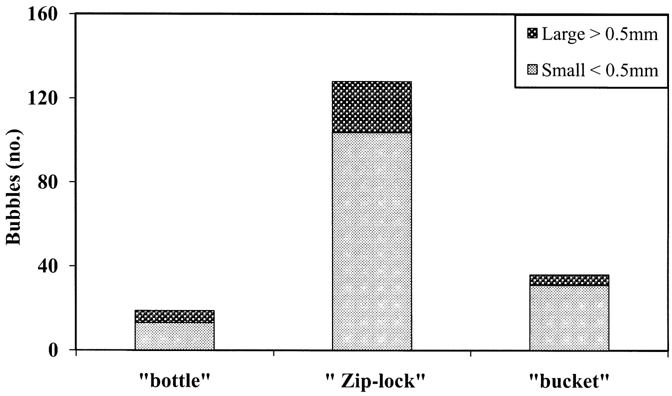

FIG. 4—*The number of air bubbles counted on casts prepared by the three different methods.*

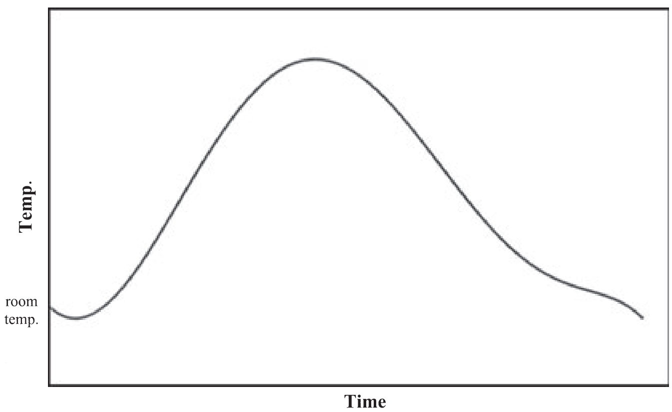

FIG. 5—*Schematic diagram for the temperature change during the drying process.*

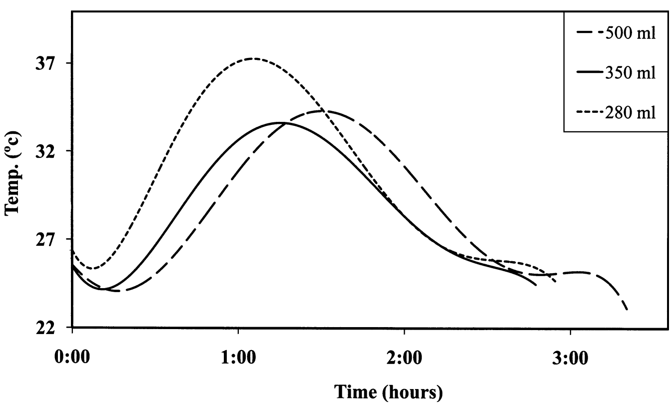

FIG. 6—*The temperature change during the drying process for different quantities of water.*

Reducing the amount of water resulted in a higher temperature peak that was reached faster (Fig. 6). As mentioned in the literature, higher maximum temperature indicates that the resultant cast will be stronger (4).

The strength of the casts did not differ from one method to the other, but the amount of water was crucial. Rubbing a finger against the back of the cast removed much powder when 500 mL of water was used, and no powder at all was removed from casts prepared with 280 mL of water. As mentioned above, this correlates with the temperature graphs and the literature (4).

The sharpness of the individual characteristics on the casts was method dependent. While the zip-lock method appeared inferior to the other methods, the bucket and the bottle seemed to achieve similar results (Fig. 7). The fine details of the minutiae were extremely sharp with both the bucket and the bottle methods, but were sometimes vague with the zip-lock method.

Optimization of the Bottle Method

Once it was observed that the bottle method can produce equal if not better casts than the two other methods, it was the authors' goal to find the optimal way to use this method.

The authors focused on the volume of water (between 280 and 350 mL) and the shaking time (between 30 sec and 5 min).

To imitate adding the powder to the water, as in the bucket method and to allow the gypsum to absorb the water prior to mixing them together, the bottle was turned upside-down immediately after adding the water, and we waited before shaking. This saturation time was kept constant −30 sec.

In the early stages of the research, it was observed that the amount of water recommended by the manufacturer (210 mL to 1 kg of dental stone) was far too small. The experiment performed with that amount of water failed, because the dental stone hardened immediately, and it was not possible to pour it into the print.

On the other hand, it was obvious that the amount of water that was used initially, 500 mL, was far too much, because several centimeters of water settled above the casts, it took longer for the casts to dry, and it produced weaker casts.

Close examination of the sharpness of the individual characteristics revealed that while 350 and 280 mL of water produced clear and sharp details, 500 mL produced some fuzzy looking minutiae.

The water that settled above the casts was visible because Biofoam® was used and not natural soil, hence the access water had nowhere to drain to. According to Bodziak (5), settling of water above the cast indicates that too much water was used.

It can be seen that a smaller volume of water resulted in a higher maximal temperature and a shorter time needed to reach the maximal temperature (Fig. 6).

When counting the air bubbles on the casts produced with different volumes of water, the smallest number was observed when 350 mL were used. The 500 mL produced the greatest number of air bubbles and 280 mL was somewhere in the middle. It is the researchers' assumption that air bubbles are trapped in the thick mixture when less water is used. On the other hand, mixing dilute fluid vigorously results in many air bubbles as well.

In the dentistry treatment of plaster casts, the mixing can be performed with a mixer or by hand. Mechanical mixing is usually completed in 20–30 sec. Hand spatulation generally requires at least a minute to obtain a smooth mix (4).

Casts prepared for forensic uses are mixed by hand. The shaking and mixing time must be determined based on practical considerations as well. Five minutes is far too long for a forensic technician to continuously shake the bottle at the crime scene. Therefore, the bottle was shaken for 30 sec, 1 min, and 2 min. It was found that the longer the mixing time the shorter the drying process. This phenomenon can be seen in the extreme cases: the 30 sec and the 5 min mixing (Fig. 8).

Discussion

These experiments show that casting dental stone using the zip-lock method is not the best method available. The casts were inferior to casts produced by the two other methods; the cuts were

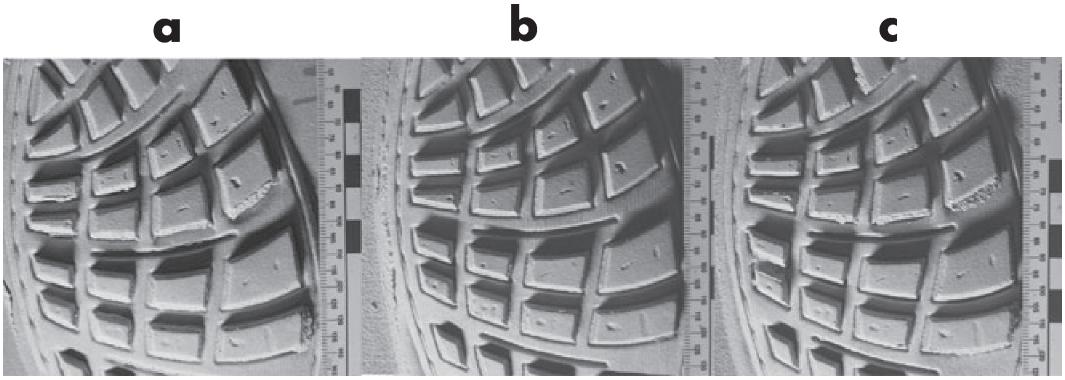

FIG. 7—*Individual characteristics on casts prepared by the different methods: (a) zip-lock method; (b) bucket method; and (c) bottle method.*

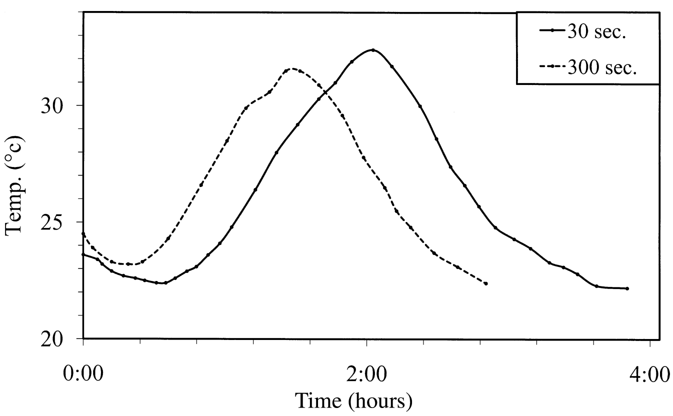

FIG. 8—*The temperature change during the drying process for different shaking durations of the bottle.*

blurry and much more air bubble interfered with the original shoe pattern. The bucket and the bottle methods gave similar results, but the application of the bottle method is much easier. The mixing is faster and easier, and furthermore, there is no need to wash the dishes after use.

Saturation of the dental powder prior to the mixing is mentioned as an important factor in making good and strong casts (4,5). This essential procedure is possible only in the bucket and the bottle methods. This fact might contribute also to the superiority of these methods over the common zip-lock method.

The influence of the mixing time on the strength and on the time needed for reaching the maximum temperature was not great. Two minutes of vigorously shaking is enough to get the optimum setting time and strength. The amount of water, however, is an important factor that was neglected in the past. Increasing the amount of water makes the mixture thinner, but the casts produced are weaker. The recommended amount of water for dental use is not valid for forensic purposes. The experiment with the recommended amount failed immediately, as the mixture hardened even before the shaking was over. The exaggerated amount of water used in the authors' laboratory was also not suitable, because it produced weaker casts with a longer setting time. The amount of water to be used in the bottle method should be between 280 and 350 mL depending on the soil temperature and other variables that may influence the setting time.

The results shown in this paper are not final, because the authors think the strength of the cast and the minimal time for taking the cast from the scene should be checked under various conditions as well.

Conclusions

The zip-lock method is the predominant method used today because of its simplicity and ease of use. The quality of the casts produced, however, is poor compared to the bucket method. The bottle method seems to give much better results than the zip-lock method while even improving the ease and comfort of use.

This study proves that despite the vigorous mixing in the bottle, not many air bubbles were noticed in the casts. Moreover, the great advantage of the bucket method is the ability to add the powder to the water and to let it soak—this process increases the strength of the cast. In this experiment, a similar process was performed in the bottle method, reaching the same affect.

The bottle method has the advantages of both the bucket and the zip-lock methods hence it combines strength, sharpness, high quality, and ease of use.

Conflict of interest: The authors have no relevant conflicts of interest to declare.

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