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Evaluation of an Innovative Casting Method in the Recovery of Footwear Impressions in Soil

تقييم طريقة صب مبتكرة لاستعادة آثار الأحذية في التربة

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Abstract

Three-dimensional (3D) shoeprints taken from crime scenes can more accurately depict impressions than photographs, providing a crucial link between the crime scene and the suspect. This paper introduces rigid polyurethane foam as an alternative material for recovering and preserving 3D footwear impressions in soil. The rigid polyurethane is manufactured through gas expansion, solidifying in a foamed state that consists of a dense integral surface and a durable closed-cell structure beneath the skin layer. It is easily molded, lightweight, dimensionally accurate, and exhibits minimal changes in strength when the foam casts are created and stored indoors. In comparison to casts made with plaster of Paris, this method produces impressions on casts that exhibit more identifiable characteristics, serving as a complementary technique for the forensic science community in reproducing 3D footwear impressions found in soil.

المستخلص

يمكن أن توفر بصمات الأحذية ثلاثية الأبعاد (3D) المأخوذة من مسرح الجريمة وصفًا أكثر دقة للانطباعات مقارنة بالصور الفوتوغرافية، مما يوفر رابطًا حاسمًا بين مسرح الجريمة والمشتبه به. تقدم هذه الورقة رغوة البولي يوريثان الصلبة كمادة بديلة لاستعادة وحفظ بصمات الأحذية ثلاثية الأبعاد في التربة. يتم تصنيع البولي يوريثان الصلب عن طريق التمدد الغازي، ويتصلب في حالة رغوية تتكون من سطح متكامل كثيف وهيكل خلوي مغلق متين تحت طبقة الجلد. إنه سهل التشكيل وخفيف الوزن ودقيق الأبعاد، ويبين تغييرات طفيفة في القوة عند إنشاء وتخزين قوالب الرغوة في الداخل. بالمقارنة مع القوالب المصنوعة من الجبس الباريسي، تنتج هذه الطريقة انطباعات على القوالب تظهر خصائص أكثر قابلية للتعرف عليها، مما يخدم كتقنية تكميلية لمجتمع علوم الطب الشرعي في إعادة إنتاج بصمات الأحذية ثلاثية الأبعاد الموجودة في التربة.

Keywords: Forensic sciences, shoe casting, footwear examination, rigid polyurethane foam, soil footwear impressions.

الكلمات المفتاحية: علوم الأدلة الجنائية، صب الأحذية، فحص الأحذية، رغوة البولي يوريثان الصلبة، بصمات الأحذية في التربة.

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1. Introduction

At crime scenes, leaving traditional features like fingerprints or DNA is relatively easy for a suspect to avoid, but avoiding leaving shoeprint marks on floors or other surfaces is more challenging [1]. To recover footwear impression evidence, the conventional methods involve creating physical casts of the impression and capturing photographs [2,3,4]. Casts are life-size 3D moldings of impressions that permit a more detailed examination than what could be achieved through a photograph. For over thirty years, police forces worldwide have utilized plaster powder as a casting material for recovering 3D impression evidence at crime scenes [5]. The quality of casts depends on the ratio of water to plaster powder, and the cast must be left for at least 2 hours to allow it to harden [6]. Additionally, the cast should be protected during shipping or storage to prevent breakage. While some new casting materials and methods for recovering footwear impressions have been explored by practitioners [5,7-9], they do not work satisfactorily for casting in soil. Polyurethane, in many aspects, is versatile compared to the aforementioned materials, offering simplicity in production and excellent formability, temperature resistance, and corrosion resistance [10,11]. This study introduces an alternative method using rigid polyurethane foam to cast footwear impressions in soil. The research aims to be explored through a series of experiments to assess the ability of rigid polyurethane foam to recover shoeprints and determine whether the foam serves as a new complementary material for crime scene technicians and examiners in recovering 3D footwear impressions at crime scenes.

2. Materials and Methods

To compare the rigid polyurethane foam with the traditional plaster method, a men's left-foot size 8 (USA), "ANTA" brand sport boot, featuring twenty-eight easily visible characteristics on the sole, was utilized, Figure 1. Three-dimensional footwear impressions were created from the shoe in soil. The rigid polyurethane foam was prepared via a two-stage method. Polyether polyol, catalysts, surfactant, and blowing agent (Component A Table 1) were added

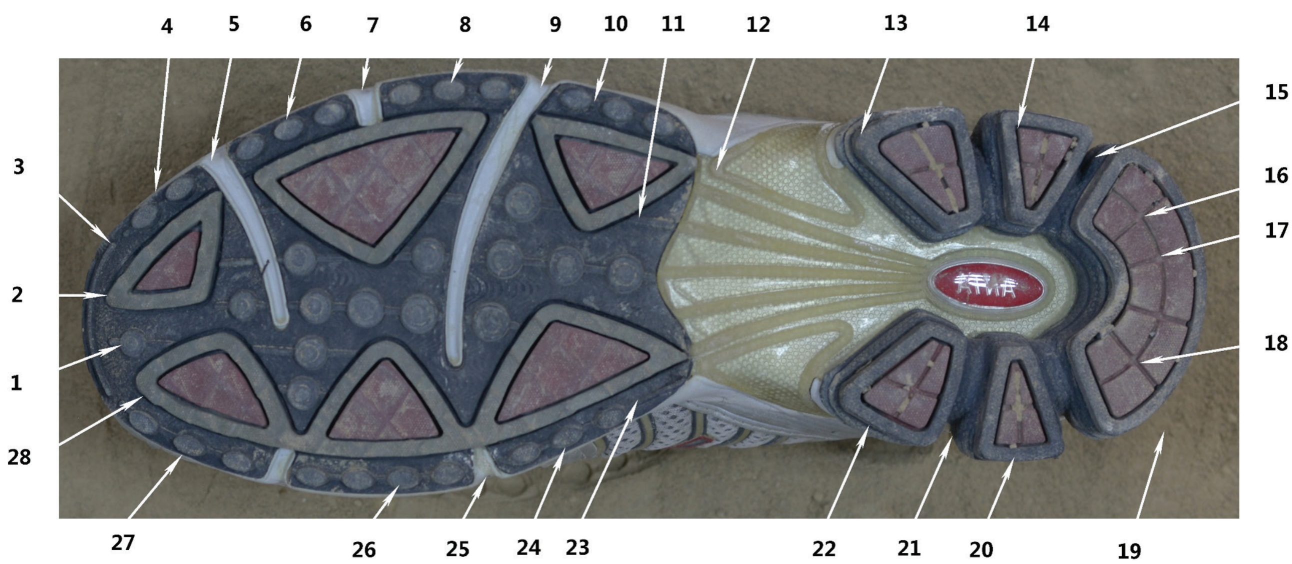


Figure 1- *The shoe sole used for the experiment with twenty eight characteristics.*

Table 1 - Formulations for a rigid polyurethane foam

Ingredients	Rigid Polyurethane Foam				
	Component A				Component B
	Polyether polyol	Catalysts (dimethylcyclohexylamine)	Surfactant (polysiloxane ether)	Blowing agent[1]	Polymeric MDI[2]
Parts by Weight	100	2.5	3.0	4.5	225

[1]water and hydrofluorocarbon (HFC R-141b)

[2]Polymeric isocyanate (PAPI 27). The quantity of isocyanate is based on an isocyanate index 120, defined as the actual amount of isocyanate used over the theoretical amount of isocyanate required, multiplied by 100.

Figure 2 - *The aluminum mold used for casing three-dimensional footwear impressions*

by weight in an aluminum cup and stirred constantly with a glass stick for 1 minute. Then, pre-weighed Component B was added to the mixed Component A for an additional 20 seconds of mixing. Finally, the reacting mixtures were poured immediately into soil shoeprints inside an aluminum mold (350mm × 150mm × 50mm) for casting footwear, Figure 2. During the polymerization reactions, the mold was pressed into the ground to a depth of 1/2 to 1 inch with a cover to prevent polymer foams from escaping. Foam casts were removed from the mold after 15 minutes, submerged in water with the aid of a soft brush to remove the sand, and cured at room conditions before measurements.

The ratio of the quantity of water to plaster powder was crucial, directly affecting the hardness, density, durability, and strength of the cast. A ratio of 0.6 of plaster powder to water was used in this research. The two components were mixed together, slowly poured into a soil impression, and evenly flowed onto each corner of the mold away from the impression, placed approximately two inches above

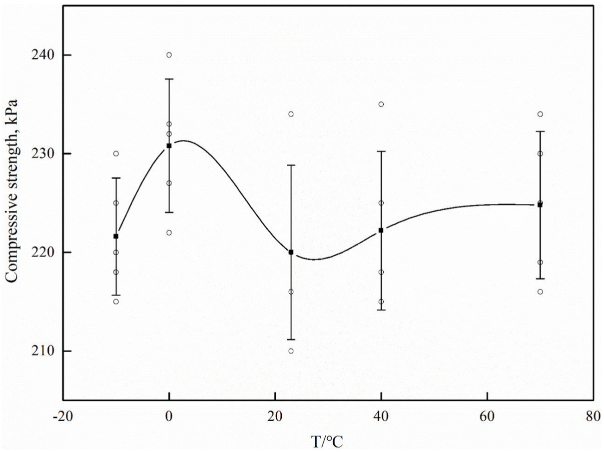


Figure 3- *Dimensional stability at specified conditions of the polyurethane foams*

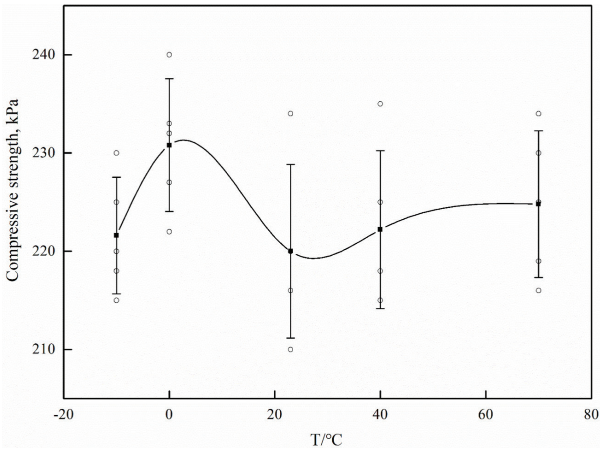


Figure 4- *Plot of compressive strength of the rigid polyurethane foam to temperature which has been at 70% relative humidity for 2 days*

the shoeprint. Wire mesh was added onto the top of the plaster cast to enhance its strength. All plaster casts were allowed to dry for 120 minutes in place, then lifted carefully. The remaining soil was lightly removed by rinsing the cast surface with water assisted by the use of a paintbrush. After drying for an additional 48 hours, the cast was stored in room conditions for further measurements.

Each casting material was used on ten casts, totaling twenty casts overall. Each cast was examined and given a simple numeral score based on the number of identifiable characteristics (0 indicating no identifiers present and 28 indicating all identifiers visible within the cast). Foam samples were cut and sputtered with gold using a sputter coater. Surface and midsection images were captured by scanning electron microscopy (SEM).

For determining the dimensional stability of the obtained rigid polyurethane foam, specimens were measured at 100 × 100 × 50 mm according to GB/T 8811-2008/ISO 2796:1986 at -25 °C, -10 °C, 0 °C, 40 °C, 70 °C, and 70% relative humidity for 48 hours. Compressive stress at 10% deformation was determined perpendicularly to the foaming direction for 50 × 50 × 50 mm samples (at -25 °C, -10 °C, 0 °C, 40 °C, 70 °C, and 70% relative humidity for 48 hours) following the requirements of GB/T 8813-2008/ISO 844:2004. Specimens were conditioned before any tests at 23 °C and 50% relative humidity for 48 hours (measured linear dimensions). The initial shrinkage was determined at 23 °C and 50% relative humidity for 48 hours after the production of 100 × 100 × 50 mm specimens.

3. Results

In the context of casting footwear impressions, the dimensional stability and compressive strength of foams are of paramount importance. Figure 3 displays the average values of dimensional stability in three directions (length, width, and thickness) of specimens. It is evident that lower temperatures result in slightly higher dimensional changes. When temperatures vary above zero, the dimensional changes in three directions for the polymer are significantly smaller. Relative changes in length and width range from 0.1% to 0.13%, and in thickness from 0.2% to 0.22%. The lowest linear changes occur at 23 °C and 70% relative humidity. For an expansion rate of 0.22% (the maximum value), a 300mm long cast would expand by 0.66mm. This

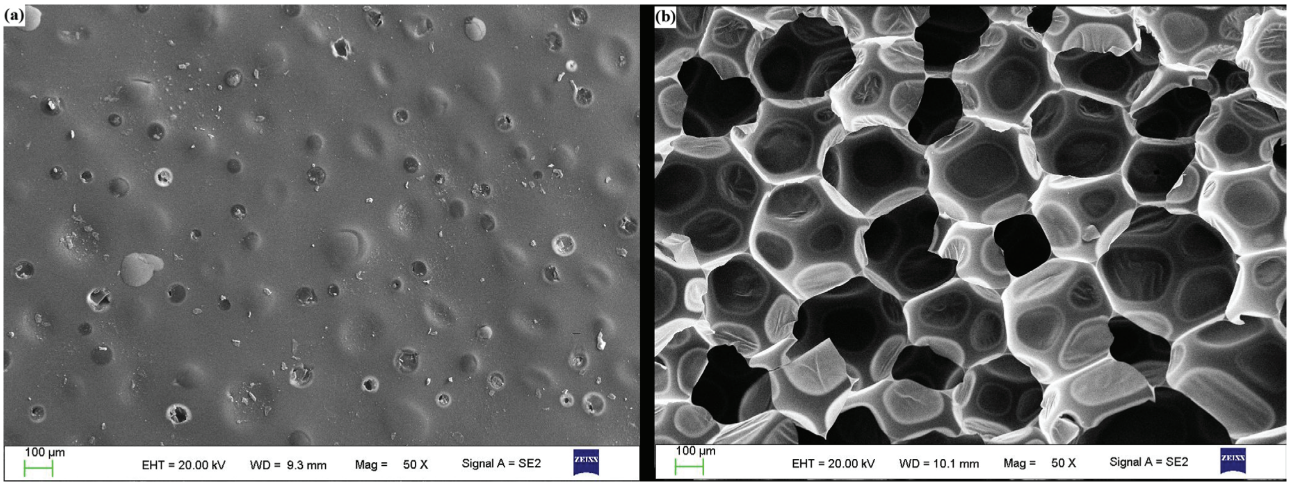


Figure 5- *SEM micrograph of the surface(a) and midsection (b) of the polyurethane foam*

minor expansion is negligible and undetectable in practical tests. Additionally, all linear changes in foam rise (thickness) and traverse (width and thickness) directions show no significant differences, indicating that the cellular structure is predominantly spherical, Figure 5b. For all practical purposes, the polymer foam casting material is dimensionally accurate when the foam cast is removed outdoors and stored indoors.

The compressive strength of polyurethane foams, tested at -10 °C, 0 °C, 23°C, 40 °C, 70 °C, and 70% relative humidity for 48 hours, is shown in Figure 4. It is observed that temperature variations do not have a significant effect on the compression strength (at 10% strain). Compressive strength heavily depends on the cellular structure of the resulting foam [12-14] and is a measure of the foam's ability to deform under loading. Figure 5b illustrates a foaming cross-linking network provided by the polymerization reaction with the formation of polyurea segments [15], resulting in stronger hydrogen bonding interactions and high stiffness [16].

4. Discussion

Molded foam casts were produced by pouring the reaction mixture into a covered mold. As the rising foam reached the mold cover and impressions in the soil, its progress was restricted. Overfilling of the mold resulted in a measured positive pressure inside the mold as the foam gelled and cured [17]. The pressure in the mold and the equalization of this pressure throughout the closed mold before the foam hardened accurately produced the shape of footwear impressions in the soil. The produced foams were lightweight, with density variations between the top and middle sections [12, 18]. Micrographs of the foam's surface and closed cellular structure mid-section are shown in Figure 5.

Figure 5a displays a dense outer layer at the foam surface, with flaw sizes decreasing to 100 µm, forming the basis of the casting design for recovering a 3D footwear impression. The dense surfaces of foam blocks are caused by the existence at the foam-impressions interface of a thin layer of noncellular polymer [19-24]. The uniformly distributed, typical closed-cell cross-section beneath the skin layer is shown in Figure 5b. The porous mid-section can be explained by a nucleation and growth mechanism, where the polymer blowing reaction rate is faster than formation [18, 20].

With only photographs, an examiner would have limited views of the features. Making a cast

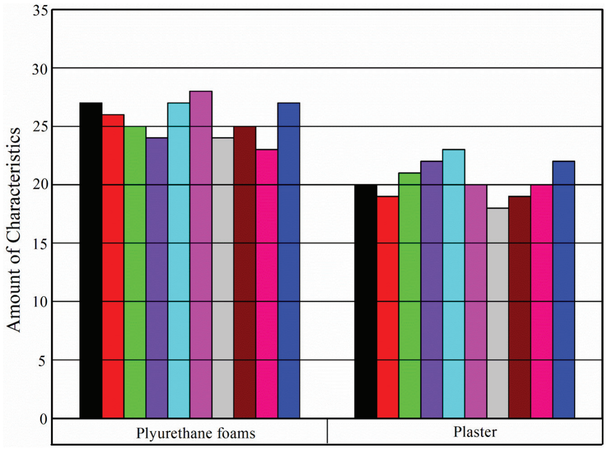


Figure 6- *Amount of characteristics visualized of the polyurethane foam and plaster of Paris*

of 3D impressions should be a regular practice, even in cases where photographed impressions appear to have limited details [5,21-23]. The foam possesses positive features such as high dimensional and mechanical properties stability, ease of deformation and handling, making it an alternative material for the accurate reproduction of 3D footwear impressions. The raw data of foam casting on the characteristics of soil-origin shoeprints are shown in Figure 6. For soil, the foams perform most successfully, with a greater number of features identified using polyurethane foams present on the shoeprints.

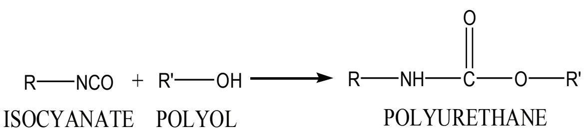
The images in Figure 7 and 8 depict two of these casts to demonstrate the versatility of this new process and material. The footwear marks developed on each casting were compared with the twenty-eight characteristics present on the known shoe in Figure 1. Overall, all the impression characteristics developed using polyurethane foams were entirely visible in Figure 7. In a comprehensive comparison, characteristics obtained by the plaster of Paris casting were lighter and more faded around the perimeter in Figure 8. For example, in Figure 7 No.1,11, the tiny lines were clearly seen with greater detail in the cast than in Figure 8. Additionally, the embossments No.16,17, and 18 were completely shadowed out in Figure 8. The results show that the more tiny footwear marks deposited on soil, the clearer the polyurethane foam casting lifted.

Plaster of Paris is the beta form of calcium sulfate hemihydrate ($CaSO_4 \times ½ H_2O$); adding water will result in gypsum ($CaSO_4 \times 2H_2O$). Casting materials such as gypsum have sufficient weight to erode and destroy valuable details when poured

Figure 7- *Characteristics on cast prepared by the rigid polyurethane foam*

Figure 8- *Characteristics on casts prepared by plaster of Paris*

onto the impression, especially critical in the case of impressions in fragile soils [5,20,24]. However, the foam casting material was manufactured by the reaction of isocyanate and polyol, which has gas expansion inside, then solidified in foam state [16,20].



The 3D polyurethane network was formed to create the footwear impression cast. The overall results indicate a noticeable difference in the impressions left on the foam casts. The rigid polyurethane foam demonstrated excellent stability in both dimensional and mechanical aspects, and its easy moldability allowed for the revelation of details that were previously hidden in the original footwear impressions.

5. Conclusion

The casting of 3D footwear impressions circumvents scale and focus problems, ensuring the accurate presentation of all characteristics to the examiner. Traditional plaster of Paris, due to its significant weight and volume, has the potential to erode and destroy valuable details when poured onto impressions, particularly in cases involving fragile soils. The versatile properties of polyurethane foams, such as excellent formability, light weight, dimensional accuracy, and minimal changes in strength, make them among the most diverse and widely used plastics. This study focuses on the examination of rigid polyurethane foams and 3D footwear impression casts to investigate the foam's properties. The rigid polyurethane foam is produced through the reaction of isocyanate and polyol, resulting in a material with a dense and integral top surface, characterized by low porosity skin, and a midsection consisting of low friability, closed-cell structures with interconnected polyurethane plates. The foam is manufactured by gas expanding, solidifying in a foamed state, and possesses properties such as light weight and easy moldability. The new polyurethane foams exhibit excellent dimensional stability and mechanical properties, showing significant promise for application in forensic cases. These foams can play a crucial role in accurately reproducing footwear impressions left in soil, aiding forensic investigations involving footwear prints.

Conflicts of interest

The authors declare that they have no competing interests.

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