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Detection of visually unrecognizable braking tracks using Laser-Induced Breakdown Spectroscopy, a feasibility study

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ABSTRACT

Identification of the position, length and mainly beginning of a braking track has proven to be essential for determination of causes of a road traffic accident. With the introduction of modern safety braking systems and assistance systems such as the Anti-lock Braking System (ABS) or Electronic Stability Control (ESC), the visual identification of braking tracks that has been used up until the present is proving to be rather complicated or even impossible. This paper focuses on identification of braking tracks using a spectrochemical analysis of the road surface. Laser-Induced Breakdown Spectroscopy (LIBS) was selected as a method suitable for fast in-situ element detection. In the course of detailed observations of braking tracks it was determined that they consist of small particles of tire treads that are caught in intrusions in the road surface. As regards detection of the "dust" resulting from wear and tear of tire treads in the environment, organic zinc was selected as the identification element in the past. The content of zinc in tire treads has been seen to differ with regard to various sources and tire types; however, the arithmetic mean and modus of these values are approximately 1% by weight. For in-situ measurements of actual braking tracks a mobile LIBS device equipped with a special module was used. Several measurements were performed for 3 different cars and tire types respectively which slowed down with full braking power. Moreover, the influence of different initial speed, vehicle mass and braking track length on detected signal is discussed here.

1. Introduction

In order to decrease the number of road traffic accidents and their consequences efficiently, it is essential to perform a correct determination of the cause of an accident and its retroaction as regards the traffic system. For an analysis of road traffic accidents, one of the most significant input parameters is information about the lengths and positions of braking tracks. Braking tracks allow for determination of, for example, the position in which the vehicle was located at the time of commencement of maximum braking action, the speed before braking, and location of the collision [1].

In practice, a method based on visual identification is used for identification and documentation of braking tracks on the road. The position of the tracks and their shapes are usually measured using the rectangular measurement method. Visible tracks most commonly start to be created when the maximum braking action is achieved, thus being shorter than the track on which the vehicle had actually been braking. The length of tracks is often measured using a measuring tape or a viameter. Creation of the tracks is gradual, and so various observers might see the beginning of tracks at various locations. It is therefore obvious that correct identification of the beginning of tracks proves to be of utmost importance as regards proper documentation of the event. Single image photogrammetry, which may be combined with an automated image analysis (as performed by, for example Wang [2] in his work), is also used for determination of the course of tracks — this method is conditional on the sufficient distinctness and distinguishability of tracks from their surroundings. The introduction of modern safety and braking systems and assistance systems has, however, caused the fact that tracks left on the road have become increasingly less distinct and optically detectable (Fig. 1).

In his doctoral thesis, V. Rábek [3] used a thermo-camera for detection and identification of braking tracks. He adopted this approach considering the fact that creation of heat or its transfer and subsequent accumulation in the road occur in the course of braking (friction between a tire and road surface) and other situations. Subsequently, tracks are determined as the areas with a different (higher) temperature

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Fig. 1. Braking tracks from car without ABS (left) and with ABS (right). The breaking tracks were made from initial speed 58 $km \cdot h^{-1}$ to complete halt by using maximum braking effect.

than their surroundings. This method is, however, significantly affected by weather conditions and, moreover, a very rapid equalization of temperatures (within several or dozens of minutes) occurs, thus resulting in a loss of information related to braking tracks.

One of the possibilities for identification of the braking tracks indistinct to the human eye is a chemical analysis of abrasion on the road surface. Descriptions of identification of braking tracks for forensic purposes using chemical analyses prove to be quite rare in technical literature. Gueissaz and Massonnet [4] used pyrolysis combined with gas chromatography and mass spectrometry for the purpose of allocation of braking tracks to specific tires. In this work, a white sheet of gelatin was applied directly to the road surface in order to collect tire tread particles (TTP) from a braking track.

Organic zinc was used for tracking of TTP in several papers, in connection with studies focused on effects of tire abrasion on the environment (e.g. [5,6]). The most commonly used analytical methods for identification and quantification of zinc in TTP were Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Electron Probe (EP) and Neutron Activation (NA). The aforementioned methods are all related to a certain disadvantage — the necessity of preparation of samples and their transportation to a laboratory. For an overview of the use of individual methods see [7]. As regards this study, we hereby propose Laser-Induced Breakdown Spectroscopy (LIBS) for identification of visually unrecognizable braking tracks. The capability of LIBS for detection of TTP and the limit of detections for various area contents of TTP were already demonstrated in our previous study [7].

The scope of principal advantages of this method comprises mainly of the relatively simple equipment, possibility to detect broad spectrum of elements without the necessity of sample preparation, relatively high sensitivity, and possibility of space resolved measurement [8–10]. Due to the abovementioned advantages, LIBS is an excellent tool for a wide range of forensic analysis, for example glass, ink or paint forensic analysis [11–13], gunshot residue detection [14,15], and latent fingerprint mapping and detection [16]. Moreover LIBS is one of the few analytical methods capable of in-situ analysis [17]. Considering the amount of zinc in tire treads and properties of the LIBS method, it seems to be highly suitable for detection of braking tracks. The objective of this paper is to prove the capability of LIBS for direct in-situ detection of optically imperceptible braking tracks. The potential to detect the position, length and beginning of braking tracks is studied in particular, since based on this information forensic experts are able to assign an appropriate car to corresponding braking track, determine initial speed, etc. Moreover this work should serve as a feasibility study before a single-purpose LIBS device is developed.

2. Theory

2.1. Braking tracks

A tire of a vehicle transfers forces (peripheral and lateral) between the vehicle and road. The scope of forces that may be transferred between the vehicle and road in this manner is limited by adhesion between the tire and road. The adhesion rate is dependent on numerous parameters such as the road surface, temperature, and road properties [18].

Should a peripheral force be applied to the tire during braking or acceleration, the speed of tire movement differs from its circumferential speed. The difference rate between tire speed and circumferential speed is referred to as sliding.

$$S = \left| \frac{v_0 - v_k}{v_k} \right| \cdot 100\% \tag{1}$$

where v_0 is the circumferential speed ($m \cdot s^{-1}$), v_k is the tire speed ($m \cdot s^{-1}$) and S is the percentage of tire sliding. If circumferential speed is not applied to the tire, its sliding is 0%, while in the case of blocking the sliding is 100%. Maximum braking power is achieved even in the event of low sliding values (approx. 20%).

Braking tracks are created as a consequence of two effects:

- The first effect is the abrading of a dirty surface layer of a road. This effect is most commonly observed in the case of heavy vehicles or in the case of higher road surface temperatures [3].
- The second effect is abrasive wear of a tire tread on a road surface. Particles created in this manner are often located just under the top of the road texture, on the side leading towards the braking location [4]. It may be anticipated that the extent of abrasive wear is proportional to sliding of a tire; however, the actual dependence is yet to be verified. In the case of intense braking at high speeds, the tire literally smelts on the road surface.