ANALYSIS OF BRAKING MARKS LEFT BY VEHICLES EQUIPPED WITH ABS WITH IR SPECTROSCOPY

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Abstract

This paper presents the possible use for IR spectroscopy to reveal skid marks left by cars equipped with Anti-lock Braking System. Detailed analysis of literature showed that there is no method that can be used in order to investigate this kind of tire marks. Up till now only two techniques have been devised. The first one is Method of Image Refinement which consists of transforming the image from the scene of the accident using dedicated graphics software. Second method includes analysis of traces using a thermal imaging camera. This study presents an innovative approach to the problem. Numerous analyses using IR spectroscopy were conducted to check the suitability of this method. The research was conducted on a Thermo Scientific FTIR Nicolet iS50 Spectrophotometer with an ATR attachment. 40 samples from 10 different types of asphalt were prepared. Each sample was measured 3 times to create its spectrum. The results were analyzed thoroughly using the dedicated SpectraGryph software. The analysis show that the wavelength which makes the braking marks visible is found within the mid-infrared range. Finally, the wavelength in which skid marks should be visible was found. This range is located in the mid-infrared.

Keywords: accident investigation, skid marks, IR spectroscopy

1. Introduction

Analysis of a road accident begins from collection of traces. Traces are factors that change an environment as a result of a collision or road accident [14,20]. The traces include both the

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arrangement of vehicles, objects on the road as well as less visible traces of glass splatters, varnish or left skid marks on the surface [8,13]. Correctly collected traces [2] can be a valuable source of information for authorities and services involved in the investigation. It enables numerous analyses and in result, the reconstruction of a car accident [1]. One of the main traces that enable estimation of vehicle speed before impact are skid marks. In traditional braking systems without ABS, a significant amount of heat is released when the wheel adhesion limit is exceeded and the tire is abraded [8,10]. The products of this process are visible on the roads as dark traces and are called the emergency braking marks [4,5]. Protection and subsequent analyses of such traces do not constitute a problem and produces relatively accurate results [16]. In newer vehicles equipped with anti-lock braking systems, wheels are constantly in motion during the braking process [15]. It results in a trace which is fainted, as compared to marks left by a non-ABS vehicle [17]. Its visibility depends on external conditions and it may not always be visible. Collecting this type of evidences proves troublesome for forensic technicians working on the scene of a road accident. When investigating the site, some misconduct may occur. Either the length of the trace is determined poorly or the trace is not revealed at all. Without information about braking distance it is very difficult to recreate crash and prove driver's guilt. In literature, no unambiguous solution to this problem was found nor any sense in which direction the research should be conducted. Due to a large scale of the problem and the lack of any sensible solutions, a decision was made to conduct a series of trials aimed at developing a methodology of universal and unambiguous collecting of such skid marks. The first series of research was aimed at comparing samples of clean asphalt with asphalt with skid mark. In this study IR spectroscopy was used as a method of identifying substances [3,19]. Corresponding results were compared to create differential spectra. The length of the wave for which the difference was most emphasized may form the basis for further analysis and the gate to solve the problem.

2. Literature review

Since vehicles with ABS were mass produced, there has been a problem with the visibility of skid marks. The first studies of the visibility of such traces appeared in the 1980s when Bosch introduced the first ABS systems in vehicles. German scientist Engels carried out a series of tests in which he braked a vehicle with an ABS system [6,7]. Then, he assessed the visibility of obtained traces. In his research, he pointed out that the skid marks were not visible on the entire length of every car under analysis. In 1990, Metz and a group of other researchers carried out tests of braking five cars with ABS on two types of surfaces: asphalt and cement [12]. Braking was performed at 105 km/h. Each vehicle left a mark on the surface, however, some of them were very poorly visible. In 1994, Lambourn conducted tests using vehicles with various ABS systems (Bosch, Teves, Girling scs, Honda ALB) on several types of asphalt surfaces [11]. He formulated conclusions that the traces of braking were visible only on surfaces containing white stone aggregation. No traces were found on the darker surfaces. There were also other researches carried out, devoted to finding a unique method to identify traces of braking of cars with ABS systems. So far, two different ways to reveal skid marks have been proposed. These are:

- Image Refinement Methods
- Thermovision method.

The Image Refinement Methods is a method initiated by Ying-wei WANG, Jian-da WU from Taiwan [18]. They carried out braking tests on a Mitsubishi Virage vehicle equipped with ABS from Bosch. The test consisted of braking at different speeds on two different surfaces with an active and inactive ABS system. Then there was an attempt to identify traces left on the road. It was found that the traces obtained during braking with the active ABS system are less contrasting than those generated during braking with vehicles without ABS system. Contrast of the first one in relation to asphalt is too low rendering it impossible to collect. Next, pictures of these skid marks were taken and then transformed using appropriate filters. This resulted in enhancing of the skid marks. Then it was possible to clearly determine the beginning and end of the braking trace of the vehicle. Photo-geometric transformations of these photos allowed to measure the braking distance of the vehicle. Research on this method was carried out only for one case. No information was found on their continuation. It should also be borne in mind that the tests come from 2003. Since then, there has been a significant development of ABS systems in vehicles, including increased accuracy by increasing the frequency of regulation. Consequently, the traces left on the road by vehicles with new ABS systems are even less visible in relation to the older ones. The above method may be ineffective. Sample image before and after transformation is shown in Figure 1.

Fig. 1. A – Image before transformation, B – Image after transformation [5]

The thermographic method is the second way to reveal skid marks [10]. During braking process large amount of heat is generated at the interface of asphalt and tires. When investigating accident scene with a thermal imaging camera, it is possible to determine exactly the beginning and end of the skid mark based on the temperature of the asphalt.

Unfortunately, this method has one major disadvantage. Traces are only visible for about 15 minutes after the incident. After this time, the trace temperature equates with the ambient temperature and testing with this method gives no results. This excludes the practical application of this method due to the fact that when a road accident occurs, team of forensic technicians appears on site much later. Sample images made by thermal imaging camera are shown in Figure 2.

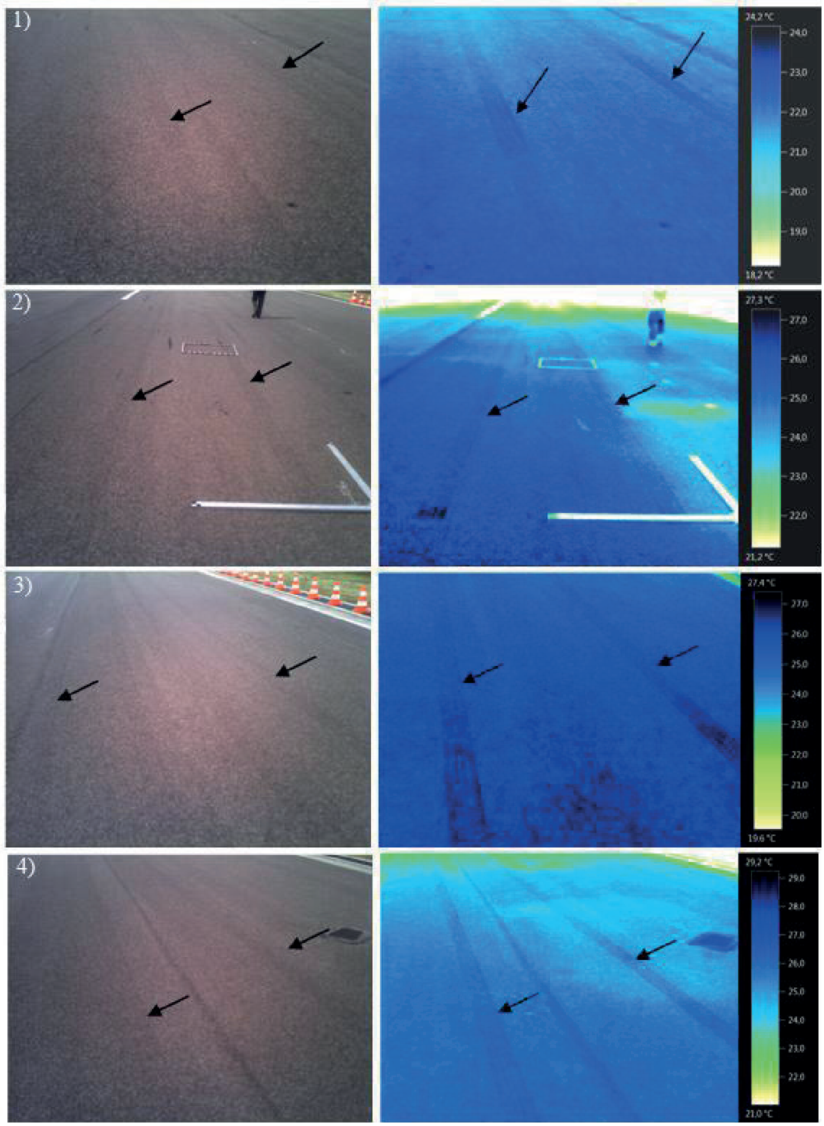

Fig. 2. Thermal image of skid mark [6]

3. Research methodology

The problem was approached in completely innovative way. Despite the lack of visibility of skid mark, a thin rubber layer remains on the asphalt surface after braking. The aim of the study was to determine whether it is possible, based on the analysis of the chemical composition of the abraded rubber layer and the asphalt itself, to distinguish these two substances apart. The main problem during the selection of the method was the fact that both substances have very similar chemical composition due to their petroleum origin. It was decided to conduct research using IR spectroscopy. It is a very precise method that allows to obtain spectra that allow to clearly differentiate tested substances. An additional advantage is short measurement time. There were 40 samples prepared from 10 different types of asphalt, 4 samples for each type of asphalt. Then, for each two samples of each type of asphalt, skid marks were applied. There were two sources of samples. One was fragments of asphalt with actual skid marks made by a vehicle. Second one was prepared by means of a device analyzing friction between the asphalt and tire. Due to this fact prepared samples meet real road conditions. From the collected fragments of asphalt cubes of 20 mm side were cut out. Sample cuboid is shown in Figure 3.

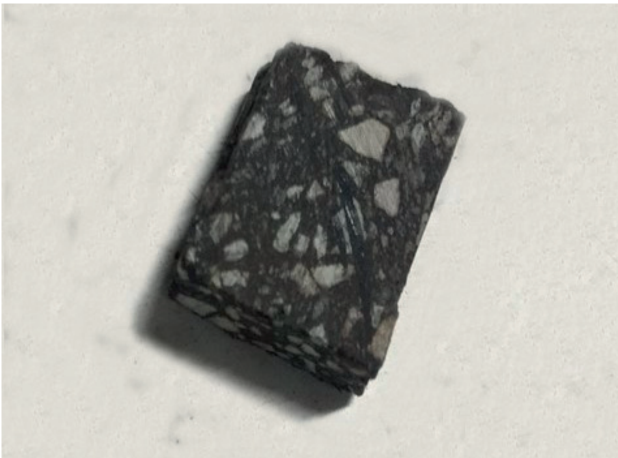

Fig. 3. Prepared cuboid.

Then samples were cleaned and degreased to remove chemical and organic contaminants that may disturb the measurement. A weak detergent was used in order not to damage the asphalt structure. The shape accuracy of the obtained samples was too low to be able to measure. Because of that they were subjected to cold working in order to obtain one plane with low roughness and sufficient flatness. For this purpose a specially prepared die was used in which the face was made of a hardened and ground element. Said die is shown in Figure 4.

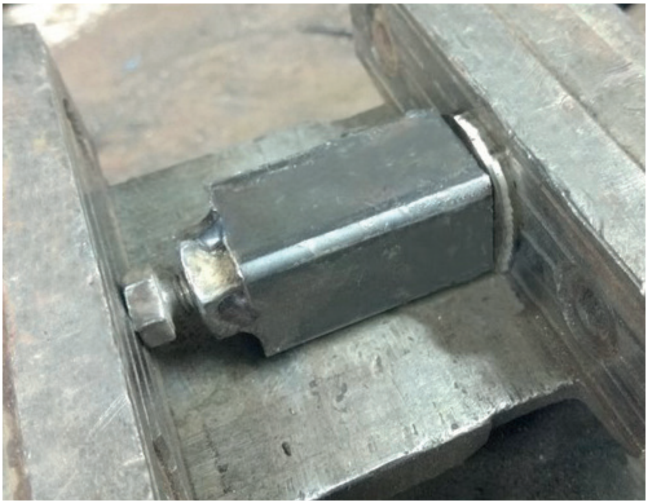

Fig. 4. Die for cold working process

Obtained samples were submerged in resin to improve their brevity. Mold is shown in Figure 5. Then skid marks were applied by special device. Prepared sample is shown in Figure 6

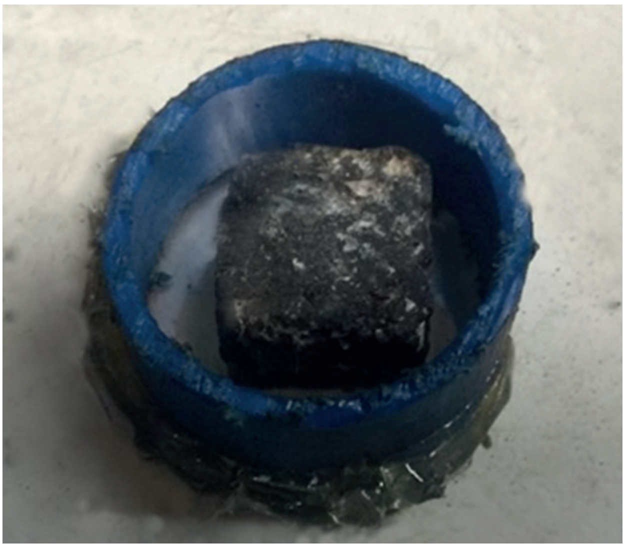

Fig. 5. Mold for including

Fig. 6. Prepared sample

The influence of slip on the visibility of the trace was omitted because the research was preliminary. In the same way skid marks were applied to 20 samples. Then samples were analyzed using a Thermo Scientific FTIR Nicolet iS50 spectrophotometer with an ATR attachment that is shown in Figure 7. Measurements were made in the wavelength range 2500 nm to 14000 nm. Each sample was measured at three locations in order to systematize the results. 120 measurements were made. The results obtained were normalized and averaged in the SpectraGryph software separately for each type of asphalt. Next, the spectra obtained for asphalt with a skid mark were subtracted from the spectrum without a trace. As the result a difference spectrum characterizing the pure trace itself was obtained. The occurrence of a local repetitive extreme for all types of asphalt would indicate a difference in the absorbance of infrared light, and thus the disclosure of the braking mark.

Fig. 7. Thermo Scientific FTIR Nicolet iS50

4. Obtained results

Figure 8 shows obtained results of differential spectra. The biggest differences in waveforms are visible in the length range from 1550 1/cm. The detailed fragment of the graph is shown in the Figure 9.

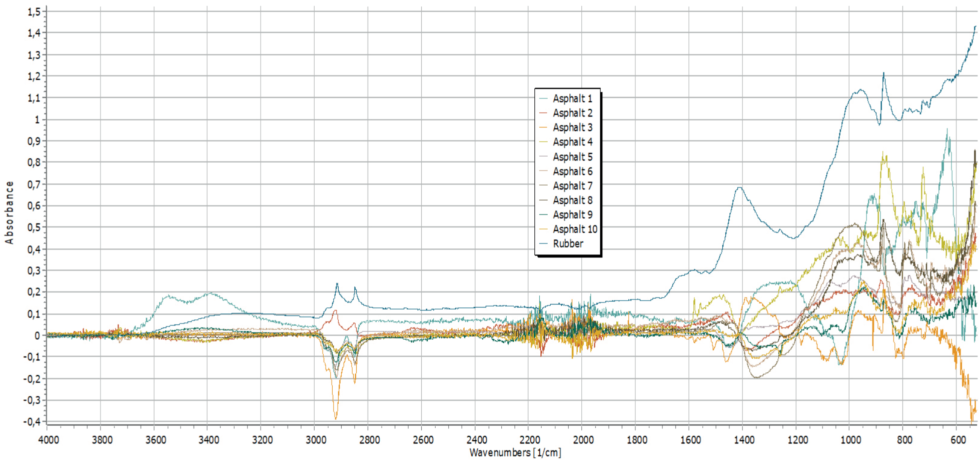

Fig. 8. Differential spectra

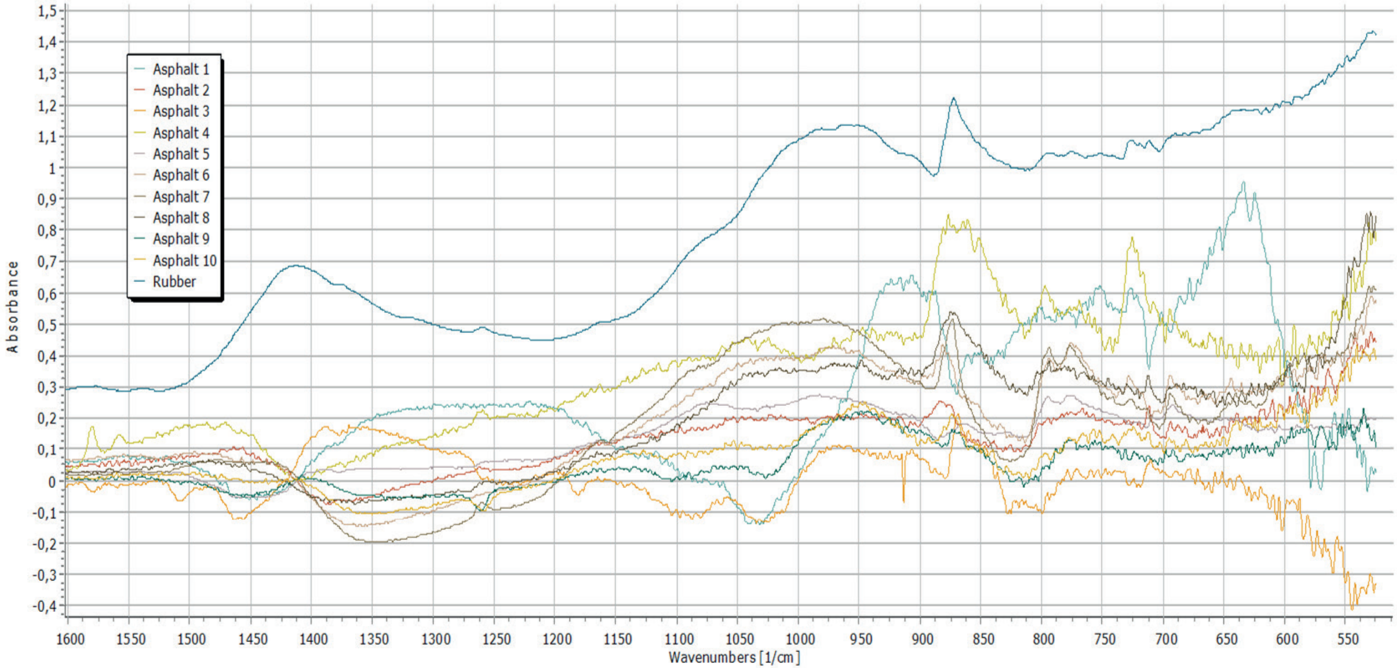

Fig. 9. Enlarger part of differential spectra

5. Results discussion

The graph shows the dependence of the absorption in the wavelength function. The measured absorption is in dimensionless units. This is due to the fact that the device with the ATR attachment was used for measurements, mainly for qualitative and not quantitative tests. Moreover, the heterogeneous character of the sample causes that the obtained absolute values of absorption depend on the selected measuring point on the sample and hence would not bring any valuable information with such a small number of measurements. The choice of the qualitative method was also dictated by the need to normalize the results. It allowed its further analysis and comparison. Two characteristic wave ranges can be distinguished in the differential plot. In the wavelength range from 2400 - 1800 1/cm, noise is visible due to the occurrence of a diamond in the path of the electromagnetic wave beam. It is an element of ATR attachment construction. Due to its properties it is completely transparent for infrared in the range of other wavelengths. Thus, high accuracy of measurement is ensured. The most interesting part of the comparison chart is shown in the Figure 8. The largest changes in absorption function are visible there. The most characteristic point is located at the wavelength 872 1/cm, that equals about 11 500 nm. These are local extreme for the majority of obtained spectra. This means that skid marks have been identified for a given wavelength. Only the spectrum for type 1 asphalt significantly deviates from the rest of the graphs. This probably indicates that during the preparation of the sample some contamination was present on the surface. Obtained spectrum of stain is probably much stronger and caused the blurring of the searched skid mark. Rest of graphs for various types of asphalt from 1 to 10 are similar to each other. The function is very similar, too. There are the same peaks for similar wavelengths.

6. Conclusions

Obtained results allow to conclude precisely that the method of analyzing brake marks in the mid-infrared range has great potential. Probably after development of appropriate measurement technology, ensuring high repeatability and accuracy of results, it will be possible to investigate skid marks left on the scene by vehicles equipped with ABS systems. Probably the traces will be best seen at a wavelength of 11,500 nm. In order to develop the measurement technology, it is necessary to conduct research on a larger number of samples using different types of asphalt and tires and controlled application of skid marks with variable slip. After such analysis, it will be possible to determine suitability of the method. It should be remembered that in real conditions, fragments of roads may also contain human or animal organic contaminants. Decomposition products of fragments of bodies and plants can significantly change the spectrum image. The above fact should also be taken into consideration during research. If positive results are obtained, it should be possible to construct a device enabling investigation of skid marks by forensic technicians. Due to the great potential of the method, as well as market demand itself, the authors of the article intend to continue their research.

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