IR spectroscopy analysis of skid marks for vehicle equipped with ABS considering slip ratio

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Abstract. Skid marks are an important source of information for road accident investigators. Up till now, analyzing them was a difficult task when ABS equipped vehicles are considered. Authors managed to solve this issue using IR spectroscopy. There are several factors to consider when investigating brake marks and one of them is slip ratio that was taken into account in this paper. Results show that for slip of 10% and more, IR spectroscopy technology was successful at revealing skid marks.

Keywords: IR spectroscopy, ABS, brakes, tire marks, vehicle, vehicle testing

1. Introduction
The problem of brake marks visibility has been known from the very beginning of the ABS system and it is unsolved to this day [1-3]. Authors decided to use IR spectroscopy to solve this problem. IR spectroscopy is a technology used to identify substances [4-6] and, according to author's opinion, it will be possible to use it to identify the braking trace at the scene of a road accident[7-10]. Preliminary studies have been performed. The results were presented in [11]. After first review and promising results, authors prepared following studies. Authors checked the influence of different types of asphalt on possibility of revealing braking marks. The results were published in [12]. In this article authors would like to present research on influence of different slip ratios for visibility of braking marks, using IR spectroscopy.

2. Literature review
Braking system equipped with the ABS improves the road safety [13-15], but on the other hand ABS caused difficulties in the reconstruction of road accidents [16-18]. There has been a problem with the visibility of skid marks since vehicles with ABS were mass produced [19-21]. So far, two different ways to reveal skid marks have been proposed. Those methods are Image Refinement Methods and Thermovision method. Both methods were precisely described in first article, where it was proposed completely new method based on IR spectroscopy [11]. As part of the research presented in this article, it was decided to investigate the impact of another parameter on the possibility of revealing braking traces at the scene of a road accident - the slip ratio. Slip is the difference between the angular velocity of the wheel minus the angular velocity of the free-rolling wheel [22-25]. Slip ratio is defined as:

$$S = \frac{V_F}{V_H} = \frac{V_H - R \cdot \omega}{V_H}$$

Where:

- \(S\) – slip
- \(V_F\) – velocity of the tire at the tire patch
- \(V_H\) – velocity of the free-rolling wheel
$V_H$ - velocity of the wheel hub
$\omega$ - angular velocity of the wheel
$R$ - rolling radius

While braking the vehicle, the slip ranges from 0% (free rolling) to 100% (wheel locked). When locking the wheels, the loss of steerability is observed. It is a dangerous situation in road traffic that makes it impossible to undertake additional defensive maneuvers, i.e. avoiding in an emergency. Therefore, it has been mandatory to install ABS systems in cars for over 20 years. ABS is a system that regulates the force acting on the vehicle brakes in such a way that the slip at the contact of the wheel with the asphalt is in the range of 10% - 30%. This range ensures that on most surfaces the maximum available braking force is used. It also enables the transfer of lateral forces arising during a turning maneuver performed simultaneously with the braking maneuver. As a result, the vehicle remains steerable during braking. Relations between slip rate and adhesion coefficient is shown in Figure 1.

![Figure 1. Relationship between braking coefficient and wheel slip [3]](image)

3. Samples preparation
140 samples were prepared for the planned research. The samples were prepared from one type of asphalt. For each of 20 samples, braking traces were applied at various slips, i.e. 0%, 10%, 20%, 30%, 40%, 100% respectively and 20 samples were left without a trace. The exact method of sample preparation and research position where the trace was applied was presented in the previous article. It is worth noting that the traces were applied on the sample in only one layer, i.e. according to the method of applying the trace in real traffic conditions. The tire pressure on the sample was 4000N and the wheel speed was 40 km / h. Traces were applied with a summer tire of a budget class. Samples photos are presented in Table 1.
Table 1. Surfaces of prepared samples.

| Slip ratio percentage | Surface | Slip ratio percentage | Surface |
|-----------------------|---------|-----------------------|---------|
| Without braking       |         | 30                    |         |
| 0                     |         | 40                    |         |
| 10                    |         | 100                   |         |
| 20                    |         |                       |         |

Table 1 shows the surface of each samples. Samples with braking marks laid down with 0% slip ratios - traces are invisible. For 10 and 20% slip ratios, braking traces were barely seen, between 30% - 40% traces are clearly visible and for 100% we can observe almost black surface. The lower slip value, the more difficult organoleptic evaluation of the braking trace is. A series of measurements were made at 3 randomly selected points of the sample. The sample was mounted to the measuring table by using the standard spectrophotometer equipment, i.e. a pressure arm with a screw. The downforce was limited by a clutch in the screw handle. Measurements were made with a resolution of 128 and a measuring gap width of 2 mm. Such parameters lengthened the time of the measurement, but allowed to obtain high accuracy. The relation between the absorption and the electromagnetic wavelength was obtained from each measurement.

Authors prepared 120 samples with traces and different slip ratios and we compared this to 20 samples without skid marks. All operations were performed by using the specialized software SpectraGryph [26], which is used to process spectra data. The results were normalized, i.e. the scale was adjusted to be able to compare the obtained values. It was a necessary procedure due to the fact that the strength of the measurement signal was different for each sample and largely dependent on the quality of the adherence.
of the sample to the measuring table. After that results were averaged to compare spectra for each slip ratios.

4. Results
Figure 2 presents the obtained results in form of a graph.

![Figure 2](image)

**Figure 2.** Graph presenting the absorbance as a function of wavenumber for different slip ratio percentages.

The braking trace was revealed on all tested samples. It was visible in the mid-infrared range, at the same wavelength as in the previous tests, i.e. 872 cm⁻¹, which corresponds to approximately 11 500 nm. At this wavelength, local absorption extremes can be noticed on the graph. The absorption value increases with the increasing slip ratios. Already at the slip ratio 10% (lower range of adjustment ABS system) local extreme is visible. It means that break trace is revealed. It is also important that for the free rolling wheel, i.e. slip ratio 0%, the absorption curve corresponds to the absorption curve for the asphalt itself. Thanks to this, in real-life conditions it should be possible to indicate the beginning of the braking trace.

5. Conclusions
Based on the conducted research, it can be stated that for all tested slip ratios it is possible to reveal braking traces. For the free rolling wheel, i.e. slip ratio 0%, the absorption curve corresponds to the absorption curve for the asphalt itself. Thanks to this, in real-life conditions it should be possible to indicate the beginning of the braking trace. Future research will investigate the effects of other factors such as tire type and pressure force. If positive results are obtained, it should be possible to construct a device enabling investigation the analysis of braking traces. Due to the high potential of the method and the market requirements themselves, the authors of the article intend to continue the research.

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