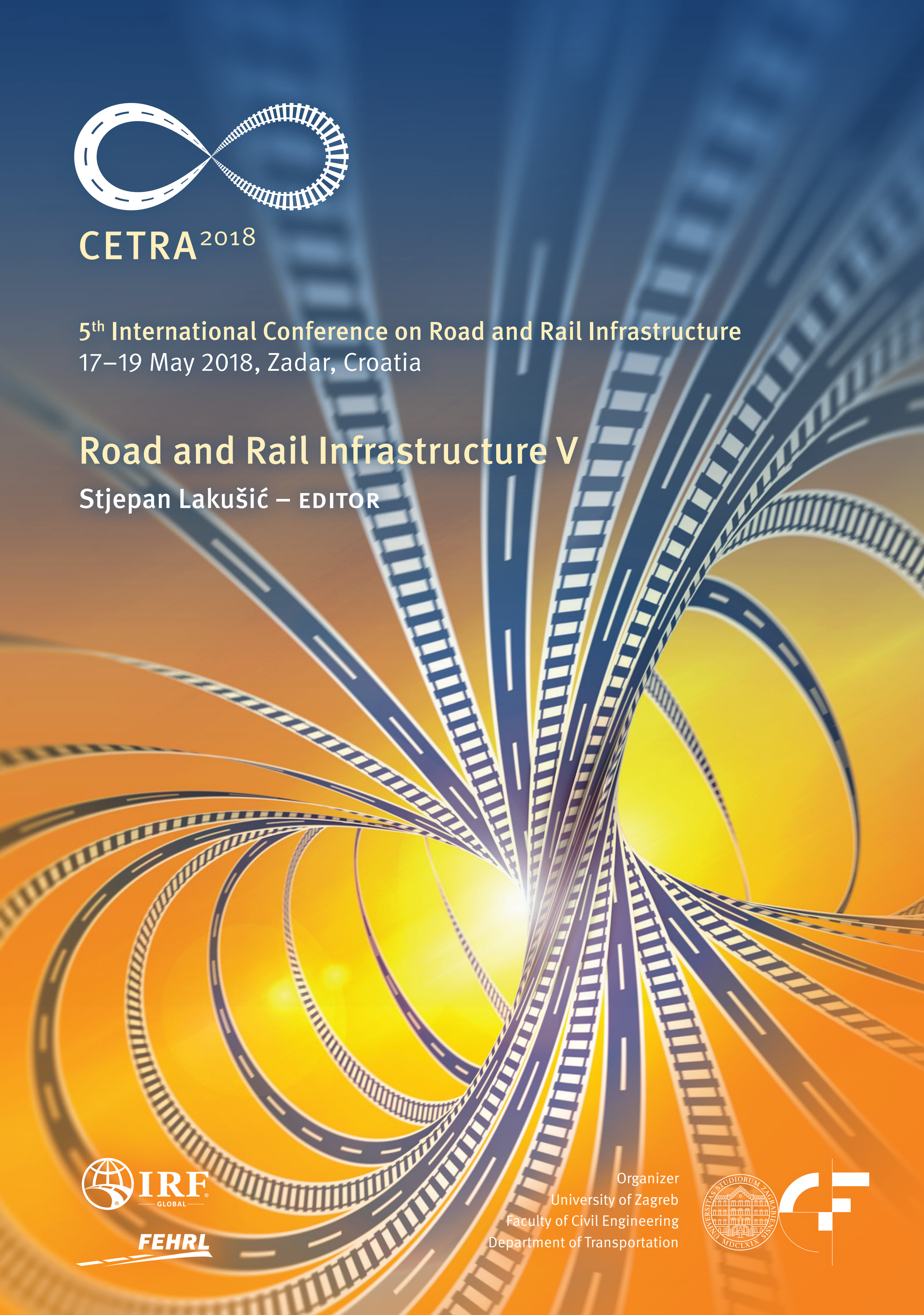

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – **EDITOR**

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ON THE IMPORTANCE OF AGGREGATE MINERALOGY IN ASPHALT PAVEMENT DISTRESS

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Abstract

Isolated and circular rust-coloured stains, joined by white or light-yellow areas, were observed on the asphaltic surface of several roads in Romania. They appear as a fine powder on the surface of bitumen-coated aggregates in the pavement wearing course. In some cases, the encountered stains were accompanied by water. A progressive aggregate stripping process occurs, which leads to potholes affecting the pavement. Asphalt mixtures are composite materials consisting of a mineral skeleton (natural aggregates and filler) mixed with a bituminous binder, following a recipe and using a specific technology. Other materials may also be added, to improve certain characteristics. Asphalt mixture samples from different affected locations were collected and investigated. No direct connection was found between the observed stains and the road cross section arrangement or the existence of ditches or drains. Microscopic analyses and X-ray diffractions were performed on the extracted asphalt mixture samples. The conducted research has emphasised degradation processes affecting natural aggregate particles in the asphalt mixture. Secondary minerals are formed following an aggregate carbonation reaction in the presence of carbon dioxide enriched water from atmospheric precipitations. Calcium carbonate (calcite), formed as the result of degradation of aggregate carbonates, was identified as the main component of the observed light-coloured areas. It is accompanied by a thin layer of iron hydroxides coating the surrounded aggregates, therefore the rust-coloured stains. It was also found that the presence of iron sulfide (i.e. pyrite, marcasite) into aggregates lead to the formation of sulfuric acid in the presence of water, which accelerates the asphalt mixture degradation processes. The obtained results demonstrate the importance of quality control during asphalt mixture production, with an emphasis on aggregate composition, mineralogy and coating.

Keywords: asphalt pavement, distress, carbonation, iron sulfide, aggregate mineralogy

1 Introduction

Asphalt mixtures are composite building materials which consist of a mineral skeleton (natural aggregates and filler) mixed with a bituminous binder, following a recipe and using an adequate technology. Bitumen is a complex and highly viscous colloidal suspension of asphaltenes in a continuous phase of saturated paraffins, aromatic oils and resins, present in natural deposits or produced from residues obtained during crude oil processing. Other materials may also be added to the mixture, in order to improve certain characteristics which influence its behaviour in operation. Asphalt mixtures are widely used worldwide as pavement construction materials [1].

The strength, resistance and durability of an asphalt mixture are influenced by several factors, including: bitumen chemistry, bitumen cohesional resistance, aggregate mineralogy,

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aggregate physical and chemical properties, absorption, aggregate surface coating, cyclic loadings and abrasion due to traffic, interaction between constituent materials, and weather conditions [1, 2].

Natural aggregates are aggregates from mineral sources that has been subjected to nothing more than mechanical processing [2]. The breaking of the adhesive bond between the aggregate surface and the bituminous binder is commonly known as stripping. Usually, the presence of moisture is the common factor to all stripping. It has a detrimental effect on the integrity of an asphalt pavement. Aggregate mineralogy and chemical composition have a significant impact on the bond between aggregates and bitumen in service [1].

In Romania, in order to ensure both aggregate and mixture performance, most asphalt mixtures are prepared using natural crushed rock aggregates, of igneous origin. These rocks result from the solidification of molten magma at or beneath the Earth's surface.

Geometrical properties of aggregates (e.g. grading, size, shape) are partly controlled and linked to aggregate processing, while other properties (e.g. mechanical, physical, and chemical properties) are an inherent characteristic of the aggregate, unaltered by quarry processing [2].

In the European Union (EU), the standard EN 13043 provides a range of specifications regarding natural aggregate properties, the associated test methods and a series of categories for each property. The chemical requirements for coarse and fine aggregates within EN 13043 are determined in accordance with EN 932-3. A coarse aggregate skeleton is a structure of grains (in the EU considered larger than 2 mm) that rest against each other and are mutually interlocked [3].

A visual examination of the aggregate, to determine the constituent rock or mineral types, is necessary. A more quantitative study implies an analytical approach, using methods such as X-ray fluorescent techniques in order to identify an aggregate's composition. All types of applied aggregates should comply with the requirements of EN 13043 selected for a specific use. Since July 2013, all EU member states have complied to manufacture all aggregates according to harmonised European standards [2, 3].

This paper presents the main aspects regarding how the analysed distress was identified and what are its main characteristics. Connections between site conditions and distress initiation and evolution were attempted. At the same time, laboratory tests on asphalt sample cores were performed. Finally, the results of macroscopic and microscopic analyses are synthesised.

2 Distress identification

During the past few years, rust-coloured stains were observed on the surface of the bituminous wearing or binder course of several roads and motorways in Romania. In most situations, they were joined by whitish or light-yellow areas (Figure 1, Figure 2). Each of these areas had a surface of approx. 1 sqm. Nonetheless, in some cases they appeared as groups of smaller stains (each with a surface as small as several square centimetres), spread over an isolated larger surface (up to 50 sqm.). The road pavement stains analysed in this paper appear as a fine powder on the surface of both active grains (those forming a skeleton and carrying loads) and passive aggregate grains (those filling the voids in a skeleton and not carrying loads).

In some cases, the encountered stains were accompanied by water (Figure 1), although it had not rained recently and the road surface was dry outside the investigated areas. Even in dry conditions (intense sunlight, temperature over 20 °C, no wind, low humidity), water could be identified in some affected areas.

At first, this was an isolated phenomenon and was rather overlooked. However, it quickly evolved to a progressive aggregate stripping process, which, under traffic and weather conditions, led to potholes affecting the pavement. Therefore, it was dealt with by local pavement resurfacing. Nevertheless, the distress not only reappeared soon enough, but it also extended and was identified on many other occasions and sites.

Figure 1 Identified distress

Figure 2 Distress details

To our knowledge, all wearing courses affected by the analysed distress were made of stone mastic asphalt (also called stone matrix asphalt), SMA. In the case of affected binder courses (made of asphalt concrete, AC), the distress was identified before the wearing course was laid, therefore rather quickly after the binder course was laid and compacted. This was one common characteristic of the affected surfaces, namely that they were all in the beginning of their service life, with most investigated stains encountered in the first year after laying the pavement. Furthermore, in several cases of pavement rehabilitation through resurfacing, the newly laid course was affected by the analysed stains, whereas the old, non-rehabilitated surface (on a different but adjacent road sector) was not.

3 Site conditions

As the identified distress was rather isolated and overlooked in the beginning, there was a general belief that the analysed stains were somehow connected to the site conditions. There were suspicions of ascensional water and cyclic hydraulic actions which led to surface seepage.

SMA surface seepage is directly related to excessive porosity of a compacted asphalt mixture and the watertightness of the binder course. Water permeability is determined not only by the void contents on the surface of a compacted course, but also by the shape and interconnectedness of the inner pores. A tight binder course, preventing the penetration of water and water vapor into the pavement, may lead to SMA surface seepage [3].

After local pavement resurfacing, the distress reappeared soon enough, as well as extending on other sites as well. Therefore, a site condition investigation was carried out, with particular attention to drainage conditions and road platform location.

The identified distress appeared in various locations, irrespective of cut or filled side slopes, as well as drainage conditions. On sites which were first affected, longitudinal drains were constructed, as this was the initial assumption regarding the distress cause. Nevertheless, the analysed stains reappeared afterwards. Therefore, it was concluded that no direct connection exists between the observed stains and the road cross section arrangement or the existence of ditches or drains.

4 Methodology

4.1 Sampling. Laboratory tests

Circular cores (100 mm in diameter) were extracted from the finished asphalt course, both in affected (Figure 3) and unaffected pavement areas from two different sites (Table 1).

Figure 3 Asphalt core sample from affected area

Table 1 Sampling locations

Site no.	Location	Distance between sites
1	Central Romania	approx. 300 km
2	Western Romania	

On site #1, the analysed distress appeared on the binder course, before the wearing course was laid. A series of acceptance tests were carried out (water absorption and compaction factor) on the extracted core samples and the results were compared with the standard requirements (Table 2).

Table 2 Core samples laboratory tests results

Properties	Measuring unit	Site	Core test results		Standard req.	
			SMA	AC	SMA	AC
water absorbtion	%	1	–	4.2…5.6	2.0…6.0	3.0…8.0
		2	2.9…5.6	3.1…5.3	2.0…6.0	3.0…8.0
compaction factor	%	1	–	min. 97.5	min. 97	min. 96
		2	min. 97.2	min. 98.2	min. 97	min. 96

The obtained results have shown that the physio-mechanical asphalt properties in both affected and unaffected areas met the standard requirements, on both analysed sites. The results of laboratory tests performed on SMA materials (i.e. natural aggregates – coarse and fine, bitumen, filler, stabilisers) were also satisfactory.

4.2 Macroscopic analysis

Macroscopic analyses were performed on coarse aggregates taken from the same batch used to prepare the affected asphalt mixture, as well as on asphalt core samples which were not tested for physio-mechanical properties. They were all analysed from a chemical and geological perspective. Sulfide minerals (specifically iron sulfides FeS_2, pyrite and marcasite) were identified on the surface of analysed coarse aggregate grains.

The observed rusty and light brown stains, sometimes joined by whitish thin crusts (max. 1 mm thickness), were identified as secondary minerals. These products were spread on the surface of active and passive aggregate grains, as well as on the inner surface of the asphalt course voids. The light-coloured crust is often joined by a thin iron hydroxide layer [4].

4.3 Microscopic analysis

The performed microscopic analyses assumed that natural aggregates from asphalt mixtures are affected by degradation processes. In the presence of water and air, different weathering processes occur and specific secondary minerals are formed, depending on the aggregate mineralogy [4].

X-ray diffractions performed on coarse aggregate samples emphasised the presence of pyrite (FeS_2) and shandite ($Ni_3Pb_2S_2$), besides silicon oxide (quartz, SiO_2). The purpose of performing an X-ray diffraction is to establish the atomic and molecular structure of a crystal. The atoms cause a beam of incident X-rays to diffract into many specific directions. Based on the angles and intensities of the diffracted beams, a 3D picture of crystal structure can be determined.

The same kind of microscopic analysis was performed on asphalt core samples affected by the investigated rust-coloured stains. The results (Figure 4) showed that those aggregates contained pyrite and marcasite (FeS_2), besides quartz and silicates such as muscovite ($H_2KAl_3Si_3O_{12}$) and anorthite ($CaAl_2Si_2O_8$).

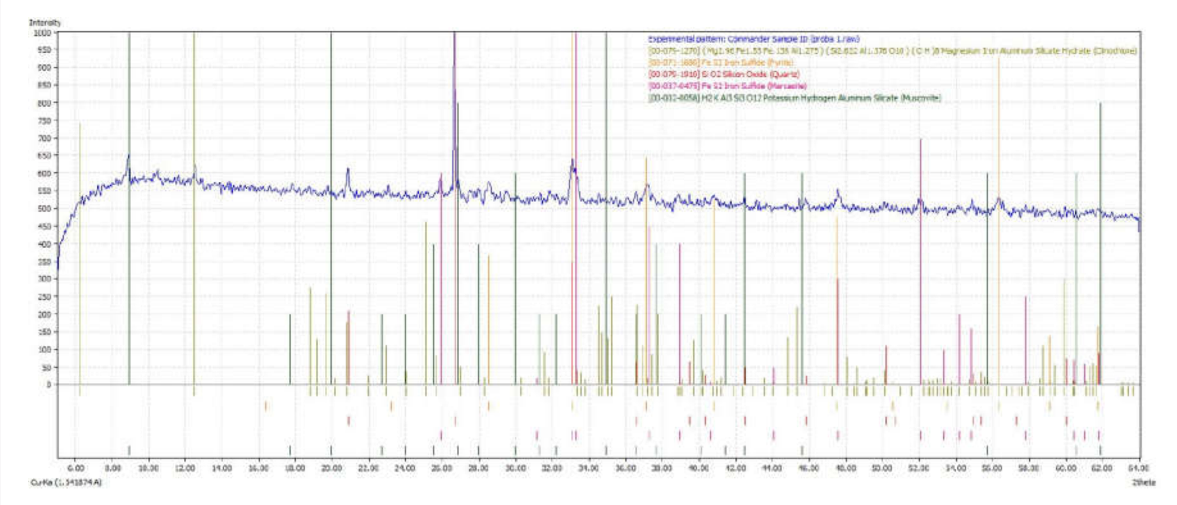

Figure 4 X-ray diffraction on asphalt core sample results

Furthermore, asphalt samples containing light-coloured stains have also been subjected to X-ray diffractions. Results have shown that those samples contain carbonate minerals, mainly calcite ($CaCO_3$), as well as siderite ($FeCO_3$) and rhodochrosite ($MnCO_3$).

5 Discussion and conclusions

The analysed stains only extend on the surface of the bituminous course and on the surface of coarse and fine grains. This suggests a series of chemical reactions that took place on the pavement surface and led to the formation of secondary minerals. It is believed that the carbonate minerals (mainly calcite) in the aggregate grains react with hydrogen ions resulted as carbon dioxide (CO_2) dissolved into atmospheric water. The newly formed calcite precipitates as the light-coloured thin crust on the surface of aggregates, especially during dry season.
Furthermore, the iron sulfides (i.e. pyrite and marcasite) identified in the aggregate grains react in the presence of water and oxygen, leading to a cyclic process involving the formation of sulfuric acid, iron sulfates and water. The resulting acid accelerates the degradation process, including aggregate stripping. These processes were also identified in the case of concrete [5, 6]. According to several sources [7-9], the identified reactions take place with volume expansion, therefore aggregate grains are displaced and potholes are initiated.
Adequate quality control during aggregate processing (extraction, crushing, scalping and screening) and asphalt mixture production, with an emphasis on aggregate grading, composition, mineralogy and coating, needs to be ensured. However, one must notice the impact of CO_2 enriched water from atmospheric precipitations on the behaviour of asphalt pavements. In the EU, in order to ensure the high quality of asphalt mixture components and to avoid aggregate degradation processes, all types of applied aggregates should comply with the requirements of EN 13043 and EN 932-3 and should be "CE" marked. Each type of rock should be carefully examined. Its description should include commentaries on its mineralogical composition, including components that may affect the final product's behaviour in time (e.g. carbonates, sulfides, silicates).
Each EU-member state specifies their quality requirements, based on aggregate availability/accesibility, long-term experience, test results and research. Annex B of EN 13043 specifies the main aspects of a suitable aggregate production quality system, including: organisation, control procedures, management, tests, transport etc. The aggregate purchaser is usually responsible to define what properties are relevant to the particular end use it is interested in. On many occasions, the producer is unable to supply consistently to a declared grade. However, the producer's responsibility is to deliver a consistent supply of aggregates meeting their claimed performance levels. Consistency is achieved through the application of a suitable and independent quality control system that justifies the right processing and inspection control levels [2].

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