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Factors affecting raveling of motorway pavements—A field experiment with new additives to the deicing brine

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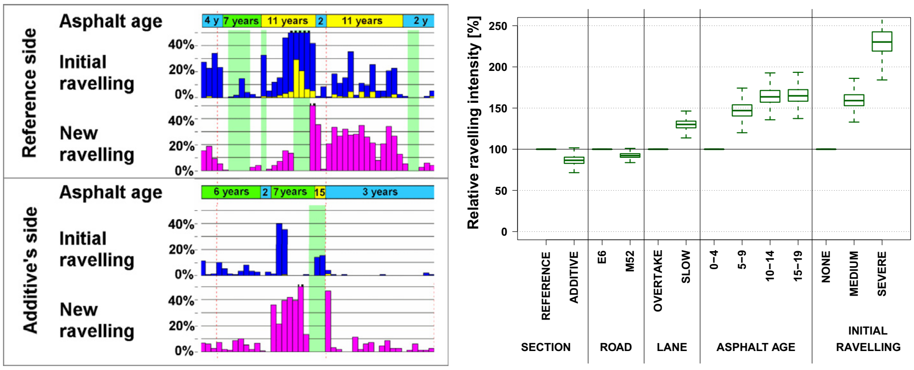
HIGHLIGHTS

- Large-scale field experiment on raveling of motorway pavements.
- The influence of different factors on raveling is estimated by statistical modeling.
- Asphalt age, initial raveling, and heavy traffic are the most important parameters.
- The novel additives to the de-icing brine reduce both winter and annual raveling.

GRAPHICAL ABSTRACT



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ABSTRACT

Recently, a novel additive to the de-icing brine has been introduced. It reduces raveling, i.e., the loss of stones of aggregate from asphalt road pavements. To assess the scale of this reduction, a field experiment was conducted. It lasted for two years and consisted of repeated measurements of 540 lane km of motorways in three European countries. Tailored statistical models were used to elucidate the relative importance of different factors influencing raveling—the novel additive, traffic intensity, asphalt age, and initial raveling. The reported results and predictive models are coupled with a detailed accuracy analysis.

1. Introduction

Asphalt materials consist of aggregates bound together with bitumen. Bitumen ensures cohesion and the flexibility of the construction, while aggregates transfer the load and provide the necessary skid resistance. The process of losing stones of aggregate from asphalt pavement is called raveling. It may lead to severe surface degradation, including the formation of potholes, as shown in Fig. 1.

Raveling is mostly studied in the context of porous asphalt, which contains over 20% voids between aggregates. This makes it more susceptible to the loss of aggregates, especially during winter, when water in the pores expands upon freezing and exerts mechanical force on the pavement structure. Raveling contributes to 90% of the surface damage on porous asphalt [26].

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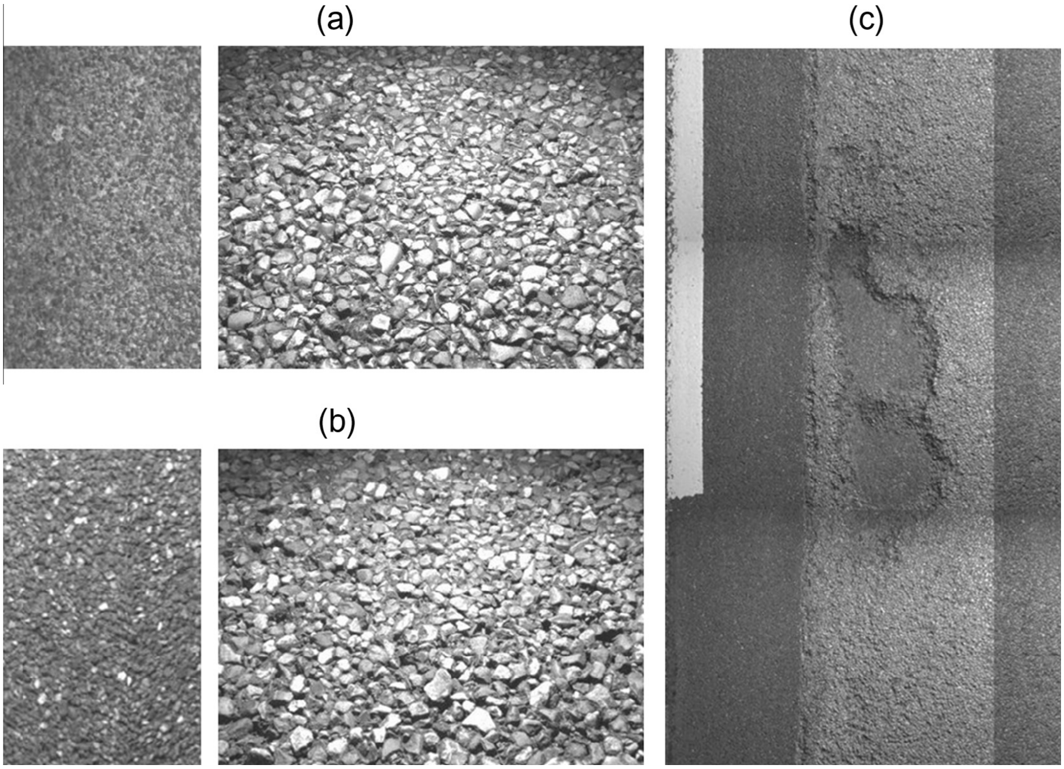

Fig. 1. Severity of raveling: (a) light, (b) medium, and (c) high.

Mechanisms of raveling can be explained through the analysis of stone-to-stone contact regions. Mo et al. [16] investigated these mechanisms using finite element modeling at the mesoscale. Raveling can either be caused by cohesive failure or by adhesive failure. Cohesive failure takes place within the binder (mastic) itself so that both fracture surfaces are still coated with the binder [27]. Cohesive failure is a consequence of confining stresses that follow from the pavement deflection under a passing tire [17] and is the predominant failure mode at high temperatures. At low temperatures, adhesive failure is predominant. It takes place at the stone–binder interfacial zone, and as a result, only one of the fracture surfaces is still coated with the binder. Adhesive failure is caused by tensile strains due to the combined effect of pavement deflection and thermal contraction [17].

Raveling is influenced by many factors including the following:

1. Quality deficiencies during the construction of road [7], such as moisture issues in mix design, cold weather asphalt paving, inadequate compaction, and the use of dusty aggregates.
2. Mix design: bitumen content, void content, percentage of coarse aggregates—especially for porous asphalt [14].
3. Mechanical stress concentration [15,14,17] resulting from heavy traffic and the use of chains or studded tires.
4. Weather conditions [8,12], in particular the number of very hot and very cold days, moisture, as well as the freeze–thaw cycles.
5. Pavement age, as the properties of binding material deteriorate in time [17,22].
6. Maintenance technology, especially in winter [7].

Multiple studies on raveling concentrate on understanding the fatigue process of the pavement, e.g., Mo et al. [18] and Zheng et al. [27] or on novel materials and treatment technologies, e.g., Liu et al. [9]. They typically concern laboratory-scale detailed experiments. In this study, a different approach is taken, namely, repetitive survey of a few hundreds of kilometers of existing motorway pavements to identify the strength of influence of different factors on raveling development. Particular attention is paid to the frost damage and winter maintenance technologies.

Ice formation can occur at different depths of the surface layer, leading to a considerable pressure. Increasing the amount of salt sprayed on the roads could reduce this problem, but it is undesirable for environmental reasons [20].

The presence of a deicer on a road does not suffice to depress the freezing point of water inside the asphalt to such level, which fully prevents frost damage. The Van't Hoff's law states that freezing point depression can only be achieved with high concentrations of small ions. Hence, there are no applicable salts more effective at freezing point depression in the most interesting temperature range (0–20 °C) than sodium chloride.

One of the promising approaches consists of using organic additives [3]. Various additives were identified that were able to keep ice in a slushy state at temperatures far below the freezing point of brine.

Recently, Maslow et al. [11] submitted a patent application on a novel additive to de-icing brine. The additive consists of molasses and a lignin derivative acting as a thickener. Lignin is an amorphous biopolymer related to cellulose and is commonly found in wood, plants, and algae. It can be rendered water soluble by sulfite pulping while introducing sulfonate or sulfonic acid functionality.

The additive consists of natural ingredients, is biodegradable, and has no Biological or Chemical Oxygen Demand (BOD/COD) issues. Moreover, no reduction of roughness of the pavement, no opacity of windshields, and no blockage of water drainage on porous asphalt were observed after its application.

Laboratory tests show that ice stays in a slushy state at temperatures far below the freezing point of the brine in the presence of the additive. At even lower temperatures, the frozen brine turns opaque instead of remaining clear and transparent. This indicates that there are more ice and di-hydrate crystals formed with than without the additive. One hypothesis is that smaller crystals are