Mitigation possibilities of concrete pavement degradation

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Abstract. Monolithic as well as precast Portland Cement Concrete pavement have shown a gradual increase in quantity and severity of defects and failures in recent years. Especially, the radical increase in the auto-destructive deterioration of the concrete structure, which is most often described as the expansion reaction, is alarming. The consequences may lead to extreme reduction of the lifetime of concrete on loaded or unloaded surface courses. The main causes are due to the combined effect of environmental effects (climate, chemical pollution), drainage of roads and the behaviour of the existing cement binders, provided that we do not reflect the modification of pavement structure layers. Only the impact of climate effects can be effectively reduced on the existing roads. The paper presents a summary of results obtained from the current portfolio of secondary concrete protection products. The testing was performed in terms of resistance to water infiltration and durability against the common effects of freeze/thaw and salt. The results show a dependence or independence according to the material basis when exposed to secondary protection products. Oils, silicate emulsions and a group with other material bases, so called other products, behave quite differently.

1. Introduction
A cement concrete pavement is a directly overrun construction layer within road pavement layers. However, surfaces on old concrete as well as on young, not resistant, concrete are at risk to fast local or full-surface material degradation [1, 2]. The extension of durability on construction sites is possible with full-surface protection. The surface on concrete pavements must be treated in order to keep their behaviour on roads [3, 4]. There are common influences caused by traffic loading or environmental erosion, physical and chemical reactions, such as an impact of chloride ions and freeze-thaw cycles, alkali-silica reactions, etc. [5]. The resistance of these deteriorations depends on concrete pavement quality, technological imperfections and conditions on site. Concrete surfaces are directly exposed to climatic conditions and have a contact with potentially aggressive substances. Concrete is a material that is hydrated for a long time for dozens of years, even though this process is reduced over time. Therefore, it needs a source of free water for its ongoing hydration. The concrete structure allows penetration or drying and movement of moisture (water). The movement is unstable over time and penetrates the system of pores, cracks and capillaries based on the current vectors of moisture and thermal gradient [6, 7].

Moisture in concrete has an effect on the vaporization and watering of the overrun surface, on drainage at the joint with subbase and moisture level at the joint with subbase at the interface with the road subbase, and furthermore, on drainage of the whole road pavement at the subgrade level. The moisture level is also significantly affected by temperature. With decreasing temperature there is a risk of condensation from air humidity, and at freezing temperature there is a risk of a part of free
water in the structure getting frozen. The part affected by frost changes with the current position of the dew point temperature in the road structure [8, 9].

Water, or moisture, is in a certain degree necessary for concrete. However, fast and significant changes in moisture in concrete and long-term surplus or long-term deficiency of moisture (water) is harmful. Significant changes in the amount and vectors affecting moisture gradients may lead to hydration product wash-out of concrete or, in contrast, to introduction of substances from the environment into concrete. In both cases the ongoing hydration could be affected.

Potential solutions regard secondary protection means. Some of them effectively reduce the magnitudes of temperature gradients by reducing water permeability while maintaining the steam permeability of concrete surfaces. Unless the amount of penetrating aggressive substances can be sufficiently reduced in time, they become reactive and harmful in the concrete structure. In those cases, we need to maintain the concrete structure in dry condition, if possible. This is not always easy, since the water source may not only come from the surface, but also from joints and other elements, or it may be in the form of capillary moisture from the bottom layers of the road pavement structure. In those cases, it is individual for each point in structure when the secondary protection means are still so effective that they could minimize expansive reactions in the concrete structure through moisture reduction, and when they are not. The requirements for the minimization of moisture changes, together with the requirement for resistance to aggressive substances, as well as requirements for resistance to frost and chemical defrosting agents, are two crucial, usually completely different, requirements that should be the technological key for selecting a specific concrete secondary protection means.

2. Materials and specimens
Concrete mixture and cube specimens (100 mm molds) were prepared in the laboratory. The mix composition used in this testing was prepared in accordance with the Road and Motorway Directorate of the Czech Republic mixing design for the exposed aggregate construction of highway surface. The selected water-to-cement ratio was 0.45, and the utilized cement was CEM I 42.5 R, which was manufactured by Heidelberg Cement Group. The coarse aggregate was limestone, gradation category Ge 90/15, with nominal maximum aggregate size of 8 mm. Fine aggregate was river sand conforming to ČSN EN 933-1 and ČSN 736123-1 specifications [10, 11]. No concrete pavement admixtures (e.g. air-entrained, superplasticizer additive, etc.) or other chemical substances were used to distort the results of the water absorption and coating effectiveness (table 1).

Ten different products of coating were selected. They were marked with numbers 1 to 10, from the available offer. Number 10 is not evaluated for its extreme viscosity, which prevents coating by sprayers. The products were applied manually by brush by one thin layer (figure 1).

Description of products:
- oil based products, numbers 4 and 9,
- silicate based products, numbers 2, 5, 6, 7, 8,
- products with other material bases, numbers 1, 3.

The secondary protection products were provided by local suppliers in Central Europe. Unfortunately, it is not possible to specify the exact product compositions, or it is not published here on request of suppliers. The material basis was determined only by the macroscopic description and classified into the groups mentioned above.
### Table 1. Mix composition of specimens.

| Component          | Density (kg/m³) | Locality   |
|--------------------|-----------------|------------|
| Cement             | 420             | Mokra      |
| Aggregate 0/2      | 692             | Tovacov    |
| Aggregate 4/8      | 1138            | Nemojov    |
| Water              | 189             | -          |
| w/c ratio          | 0.45            | -          |

The results are subsequently converted and put into a graph as a relative value of water saturation (infiltration) against the same and equally tested specimen without any secondary protection “REF Concrete” (see paragraph 4.1).

![Cube specimens coated with products of secondary protection](image)

**Figure 1.** Cube specimens coated with products of secondary protection: a) oil-based products, b) other based products, c) silicate-based products.

### 3. Experimental methods

The currently effective standard for concrete is ČSN EN 206+A1 [12]. This standard works with a term “working life” and “environmental actions”. Regarding expansive reactions, the alkali-silica reaction of aggregates and reactivity of carbonate aggregates are mentioned. Concrete resistance to effects of water, frost and defrosting agents is ensured by a right selection of environmental actions; in the Czech Republic the testing is performed according to ČSN 73 1326 (potentially according to ČSN 73 1322 and, if required, according to EN 480-11). Secondary protection is not a separate article according to this standard [13–16].

Regarding secondary protection, the closest to concretes is EN 1504-2 “Products and systems for the protection and repair” [17]. It uses terms “Hydrophobic impregnation”, “Impregnation” and “Coating”. The standard concerns all concretes and mentions five suitable principles. For the needs of cement concrete pavements, the crucial principles are principle 1 (PI – protection against infiltration) and principle 2 (MC – moisture control). Less important are usually principles 5 (PR – physical resistance), 6 (RC – resistance to chemicals) and 8 (IR – increasing resistivity).

The following tests are related to recommended tests for principles 1 and 2:
- water infiltration rate,
- water steam permeability,
- water penetration depth.
In order to compare the effect of secondary protection against water penetration into concrete, we designed our own model test “Water infiltration rate in concrete”. The test is performed on laboratory specimens that are, at the age of 28 days, dried to the minimum weight, weighed and then left for at least 7 days under water up to the maximum weight, and weighed again. After keeping them at 20°C and relative humidity of 50%, “balanced” moisture is reached, and coating is performed along the whole perimeter by a secondary means. After the coating dries, the specimen is ready for the test itself, which is based on the immersion for 2 hours in water, wherein it is continuously weighed every 15 minutes by laboratory calibrated scale with an accuracy of 0.01 g (figure 2a).

Afterwards, the test “Water infiltration rate in concrete” on the same specimens was accompanied with tests in the environment of frost and salts according to the existing ČSN 73 1326 in KD-20 chamber, i.e. with specimens pre-saturated in water (figure 2b).

**Figure 2a.** Water infiltration rate testing of cube specimens coated by products of secondary protection (specimen coated by silicate-based product No. 2).

**Figure 2b.** Resistance of cement concrete surface to water and defrosting chemicals testing, KD-20 chamber with all specimens.

### 4. Results and discussion

#### 4.1. Water infiltration

In literature, water infiltration is accepted as a parameter related to concrete durability. The water absorption by immersion gives an estimate of the total pore volume of the concrete surface, but gives no indication on the concrete permeability, which is more important regarding durability [3, 18]. This testing method can be used to verify short-term surface water absorption and coating agent effectiveness, since water and other applied agents may cause the concrete destruction [5]. If we ensure lower absorption of concrete, we can increase its resistance. Absorption tests could be used as a quick testing method when the results provide us with an idea of the total water infiltration content over a certain time period [18].

The result of “Water infiltration” test is shown in figure 3. Figure 3 shows the percentage of relative water saturation differences between values of each individual product during the test after 15 minutes. Water saturation was measured using precision laboratory calibrated scale for two hours. Results showed that all coating products reduced water saturation of the concrete surface but with different effectiveness in comparison to the reference specimen of ordinary Portland Cement Concrete (REF).
Figure 3. Water infiltration rate results for all groups: silicates (No. 2, 5, 6, 7 and 8), oils (No. 4 and 9) and other material bases (No. 1 and 3).

Generally, we cannot say that some material bases have equal or at least similar water intrusion characteristics as well. The “silicates” groups (No. 2, 5, 6, 7 and 8) have extremely different effectiveness, which is probably due to the composition of each product. On the other hand, it appears that the "oil" products (No. 4 and 9) have similar effectiveness.

4.2. Freeze-thaw resistance

It is expected that penetration of impregnated matrix by destructive agents (e.g. chloride ion) may also be reduced in comparison with the unimpregnated matrix. In contrast, several studies have showed that effectiveness of different types of surface treatment materials may vary depending on the exposure conditions. For example, a study by Suleiman, et al. showed poor performance under sulfate attack on concrete protected by a silicate agent. Another study showed that using silane as a surface treatment material enhanced the durability of concrete that was fully immersed in a sulfate solution compared to sodium silicate [3]. Therefore, caution is required to select the appropriate concrete coating material for different exposure conditions. Regarding concrete pavement, freeze-thaw resistance against defrosting chemicals is important.

The results of freeze-thaw tests show that the resistance of coated specimens is higher than the non-coated ones. Coated specimens are generally considered more effective based on the reduction of the amount of penetrated chloride ion, therefore, the destruction of concrete after testing is not too fast and extensive [1, 18].

The total mass of scaled material related to the test surface after each measuring interval is evaluated, in g/m². Measurements of surface scaling are performed at the beginning of the freeze-thaw test (0 cycle) after 25th and 50th freeze-thaw cycle. The scaled material from the specimen surface after 25(50) freeze-thaw cycles in 3% NaCl solution is shown in Figures 4a and 4b. According to freeze-thaw test results, the lowest surface scaling was obtained from oil applied specimens (No. 4 and No. 9). We can say that the “silicates” groups (No. 2, 5, 6, 7 and 8) have extremely different resistance results.
Figure 4a. Scaling of concrete surface after 50 freeze-thaw cycles (specimen coated by silicate-based product No. 2).

Figure 4b. Relative scaling of concrete surface for all groups: silicates (No. 2, 5, 6, 7 and 8), oils (No. 4 and 9) and other material bases (No. 1 and 3).

5. Conclusions
There is a huge number of different types of impregnation materials and techniques which should be investigated in further studies in relation to finding smart solutions for pavement maintenance. This article deals with the influence of secondary protection products of concrete pavement and different effectiveness of selected parameters. Researched products were composed of oils, silicate emulsions or other “non-detected” bases and the impact on water absorption and freeze-thaw resistance of laboratory specimens was monitored. Based on the results, it can be concluded that:

- According to laboratory testing, it was found that there is no general dependence between the parameters of the concrete absorption and the resistance of cement concrete surface to water and defrosting chemicals. The currently offered portfolio of coating products is able to improve only a single monitored parameter but hardly both of them.
- Current testing has an insufficiently accurate test portfolio to verify secondary protections.
- Road diagnostics to determine the cause of failure must be performed individually for each pavement structure or construction to reach a decision which parameter we need to improve by the coating.
- Moreover, concrete surfaces of different ages may react differently to coating effectiveness.
- Secondary protection on the basis of linseed varnish oil proved to be very successful in the Czech Republic in the past but is not environmentally friendly. Therefore, new development of oil products has potential for research in the future. The long-term testing and monitoring of surface properties for traffic safety, e.g. anti-skid testing, needs to be used on highways.

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