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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EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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ANALYZING THE DURABILITY OF ADHESION STABILITY OF ASPHALT MIXTURES

Tereza Valentová, Jan Valentin
CTU in Prague, Faculty of Civil Engineering, Department of Road Structures, Czech Republic

Abstract

Adhesion is one of the fundamental characteristics related to asphalt mixtures. It determines significantly the durability of asphalt mixture and depends not only on the quality of aggregate particles coating but also on the hydrophobity or hydrophility of the aggregates. For this reason often mineral-based or chemical additives are used to improve adhesion between bitumen and aggregate particles. Mainly with the latter group of additives long-term stability is connected. Amine based additives are often used which unfortunately contains easily volatile compounds. If part of the effective substance is evaporated during mixing and paving the later durability can be negatively influences. Therefore it is important not only to assess the adhesion when virgin bitumen and aggregates are used, but also the artificially aged binders or asphalt mixtures have to be evaluated. For this reason long-term research is in progress at the Czech Technical University in Prague focusing on different aggregates (different mineralogy) and different adhesion promoters. Tests are run on virgin materials as well as on specimens long-termly aged (either bitumen by RTFOT+PAV or 3xRTFOT/TFOT, or asphalt mixtures which are usually aged for 5 days at 85 °C). For bitumen-aggregate adhesion determination a standardized procedure according to CSN 736161 is performed. For asphalt mixtures the water susceptibility test according to EN 12697-12 is done on Marshall test specimens compacted by 2x25 blows. The paper presents some of the findings, including the impact of long-term ageing effects.

Keywords: adhesion stability, adhesion promoter, water susceptibility, asphalt mixture.

1 Introduction

Adhesion between the bitumen and aggregate combined with the durability of asphalt mixtures is a very important topic that is continuously researched for many decades, and there is still no consistent methodology. Often overlooked factor is the long-term effect related to adhesion quality between bitumen and aggregates. In fact, many factors that cause adhesive or cohesive failures, are affecting the pavement and there is no exception during simulation in laboratory conditions, however, it is necessary to consider properly the conditions of the surrounding (traffic, climate).

Water susceptibility ranks amongst key causes of hot-mix asphalt (HMA) failures. In cases where the internal bonds between the binder and aggregate weakens due to water presence on the aggregate-binder interface, the mixture may be considered susceptible to humidity and water effects. If the bond between the aggregate particle and binder deteriorates, it is in general called a loss of aggregate-binder adhesion process. Test methods quantifying e.g. asphalt mix resistance to water in compacted test specimens may be applied to determine the degree of damage or asphalt mix susceptibility to the negative effects of water. The test method, or results thereof, give an indication of the possible potential of long-term adhesion

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loss of the individual aggregate particles due to water and, simultaneously, may be used to assess the effect of adhesion promoters on improved resistance to water. The Czech Republic applies a very simple test method based on a subjective assessment according to national standard CSN 73 6161 to determine the binder-aggregate adhesion or the degree of mineral particle coating, similarly to some procedures which are defined in EN 12697-11, [1-4].

2 Additives

To improve adhesion between the binder and aggregate or water susceptibility of an asphalt mixture, application of various types of liquid-form chemical-based additives is used. Liquid forms of additives added to the hot bitumen are usually organic surfactants which reduce surface tension, allowing superior coating of the individual aggregate particles and, ultimately, stronger bonds between the binder and the aggregate – the hydrophilic behaviour of the aggregate is reduced. The market offers a number of such additives; the choice of a suitable additive depends on the origin of the aggregate used, the mineralogy as well as the type of bituminous binder and temperature of asphalt mixture preparation.
This paper compares practically well-known as well as less used chemical surfactants comprising amines, amido-amines, silanes etc. For avoiding any commercial preferences AH, IP, WE marked additives were applied in the same content of 0.3 M% surfactant added to a same paving grade bitumen as well as the use of nanochemical based additive ZT in the dosage of 0.1 M%. For comparison, AH additive and IP additive were dosed in higher content of the surfactants in the binders (0.6 M%) as well, [5, 6].
For a broader comparison of the effects of well-known liquid additives for the purpose of bituminous binder modification, another group of newly developed products of adhesion promoters was applied in the next step. Additives marked TA and TC are products based on alkylsilanes and additives AD and ADM are a reaction product of unsaturated fatty acids combined with diethanolamine. These additives were dosed in amounts of 0.2 M% and 0.4 M% to similar paving grade bitumen. To facilitate definition of the effects of individual additives, a reference mixture with no additives was included in the test as well.

3 Results delivered by the research

3.1 Determining of bitumen to aggregate adhesion

The non-harmonised quality test of bitumen to aggregate adhesion was conducted and evaluated according to the Czech national standard CSN 73 6161. The sample of aggregate was coated by a specific amount of bitumen. Subsequently, the sample in a glass vessel was stored for one day dry at room temperature, and then was conditioned in water using temperature of 60±3 °C for 60 minutes. According to CSN 73 6161, bitumen to aggregate adhesion is evaluated using a similar system as in the case of method B given in the harmonized standard EN 12697-11. Unsatisfactory evaluation is the in case that less than 75 % particles have the C characteristic (quality of coating). The test involved 8 different types of aggregate and one bitumen representative improved subsequently by selected chemical adhesion additives. The selected types of aggregate represent different types of petrographic composition, which can be found normally in the Czech Republic. Figure 1 summarises the results of unaged binder which indicates the results of one version with reference binder only and the results of a combination with a selected adhesion promoter for each aggregate type. The results were assessed as unsatisfactory for the binder with no additives and aggregate types clinkstone and mixed rock (ash rock, metatuf and spilite) and also in case when granulite was used as aggregate. The positive effect of the additives could be proven for all types of aggregate. On average, the percentage of coated surface of the aggregate increased by 10 % when each individual additive was applied. A higher dose of additives resulted in a slight improvement of adhesion of the individual aggregate variants; or at least the adhesion did not deteriorate. The only exception was the higher dose of adhesion additive AH, where adhesion deteriorated; however, a repeat measurement was recommended for this case, [5, 6].

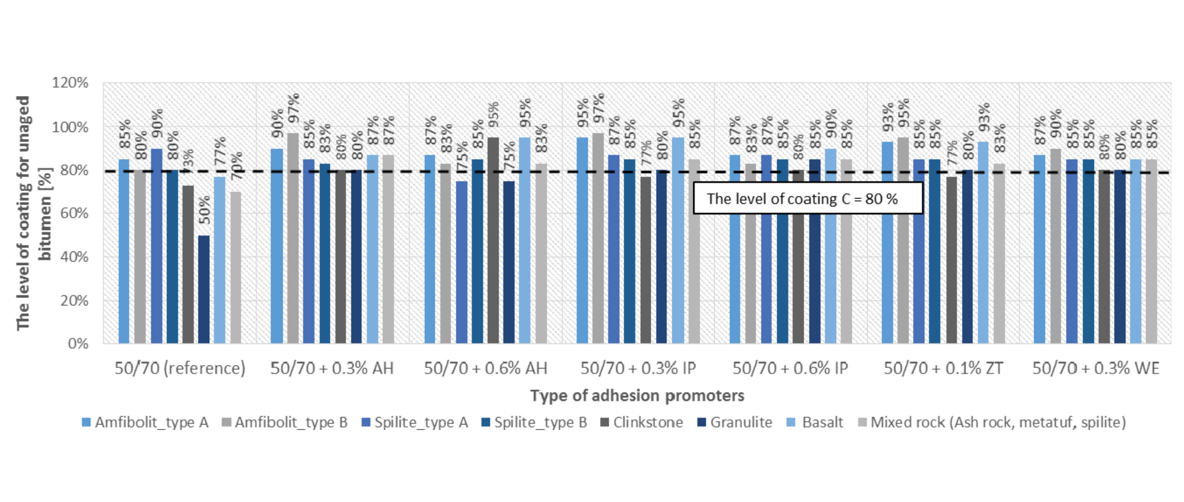

Figure 1 Determination of adhesion between the bitumen and aggregates according to CSN 73 6161 for unaged bitumen (NOTE: The standard CSN 73 6161 evaluates bitumen to aggregate adhesion as unsatisfactory if less than 75 % of aggregate particles has the coating characteristic C)

Figure 2 presents a comparison of three different types of aggregate with new formulations of chemical surfactants on the basis of alkasilanes or unsaturated fatty acid compounds, wherein the main carrier is paving grade bitumen 50/70. The chart in figure 2 demonstrates that only 60 % of the total surface of individual aggregate particles were coated in the reference sample using just paving grade bitumen in combination with granite porphyry, and only 40 % in combination with granodiorite. In contrast to that, a mineral mix achieved an 80 % coat which is a satisfactory score under the standard CSN 73 6161. With this type of rock, the application of additives results in further improvement of aggregate particle coating by the added bituminous binder; even up to 87 % in the case of adding 0.4 % of TC. Focusing on the remaining two types of rocks (minerals), the application of adhesion promoters facilitates an improved level of coating in the case of the higher dose of additive, 0.4 %.

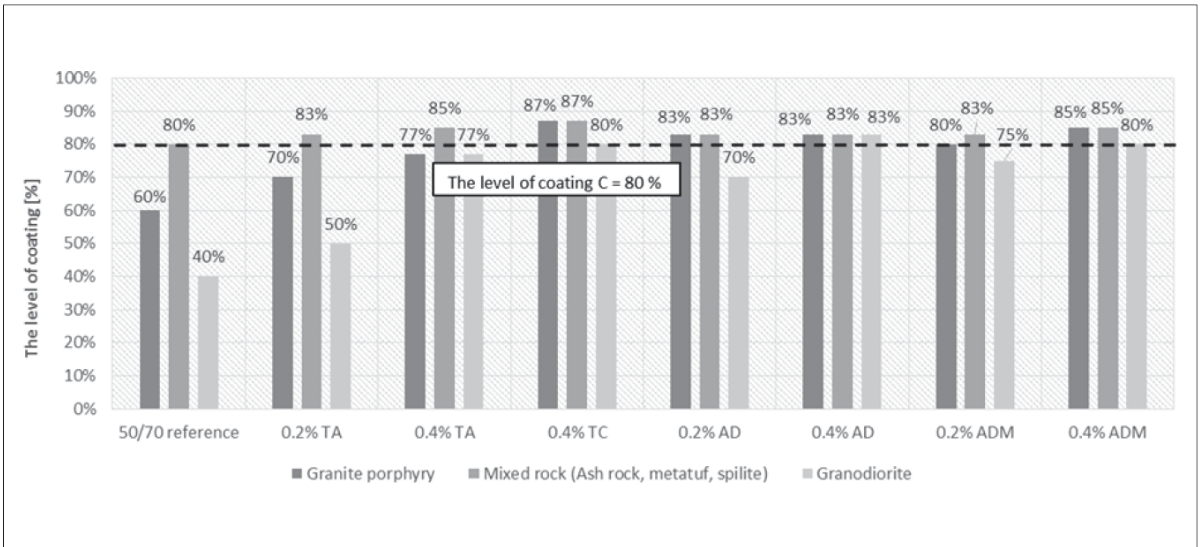

Figure 2 Determination of adhesion between the bitumen and aggregates according to CSN 73 6161 for unaged bitumen

3.2 Determining of stability of bitumen to aggregate adhesion by long-term ageing

An important aspect in the application of adhesion promoters, primarily in the case of chemical additives, is thermal stability. Under standard conditions where the asphalt mix producer processes the mix immediately after preparation, or uses bituminous binder without storing it unnecessarily long, the point of view is important solely in respect of the long-term effect of the adhesion promoter in the pavement. If the bituminous binder, already containing adhesion promoter, must be stored for extended periods at higher temperatures, there is a risk that the chemical ingredients or compounds of an adhesion promoter will be volatilised. Therefore, new chemical solutions are searched for in this regard, like for instance amide-amine groups of chemicals which demonstrate superior stability under higher temperatures in the long term. However, what is still largely ignored is the effect of long-term ageing occurring after the asphalt layer application and associated with progressive oxidising in combination with UV radiation effects on the bituminous binder over the pavement lifetime. The main source of long-term ageing is oxygen from the air, along with UV radiation, intensified by other influences over the pavement structure. This paper aims to verify thermal stability of adhesion promoters applied to the asphalt mixture as such.
To verify the effects of adhesion promoters, the variants of binders were subjected to accelerated long-term ageing (3xTFOT), which is based on the Rolling Thin-Film Oven (RTFO) procedure for short-term ageing of asphalt binder according to CSN EN 12607-1. The binder was exposed to ageing effects for three times 5 hours at 163 °C. The 3xTFOT method was chosen as a simpler alternative to a Pressure Ageing Vessel (PAV) method. Focusing on the comparison of the aged binder (Figure 3), the results are arranged logically as in the preceding case. As is obvious from the measurements, contrary to expectations, ageing has a positive effect on the adhesion of bituminous binders to aggregate at least if the test procedure according to CSN 736161 is used for adhesion determination. Based on the majority of results, it can be noted that the level of aggregate particles coating by bitumen improves, or the remaining specimens do not demonstrate a deterioration of adhesion. In the case of the reference sample with bitumen 50/70, using the aggregate granulite and mixed rock, the coating level improved due to the influence of ageing time [7, 8].

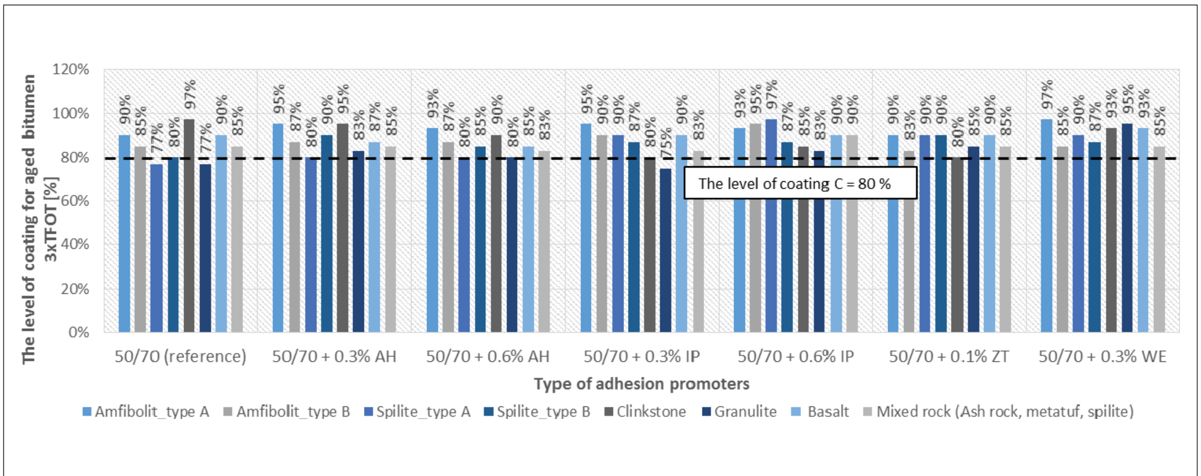

Figure 3 Determination of adhesion between the bitumen and aggregates according to CSN 73 6161 for aged bitumen 3xTFOT

3.3 Resistance to water susceptibility – ITSR

The moisture damage is generally defined as the degradation of the mechanical properties of the material due to the presence of moisture (water) in the microstructure and contributes significantly to premature failure of asphalt pavements. For the purposes of assessing the effect of adhesion promoters, from the perspective of adhesion and water susceptibility, mix ACbin 16 intended for the binder course was designed. The aggregate for the mixture originated from the Sýkořice quarry near Zbečno (spilite) and the Brant quarry not far from Rakovník (granite porphyry). The determining moisture susceptibility test was conducted in compliance with technical standard EN 12697-12. This standard method was completed by the US Standard ASHHTO T 283-03 including one frost cycle. Based on this second test it is possible to take into account not only the effect of moisture damage but also the combination with the effect of water freezing. The results of both test methods is the ratio between indirect tensile strength of the water-saturated (or combination with frost cycle) test specimen group and test specimens kept dry at laboratory environment, known as ITS ratio. When this test method is applied for asphalt mixtures in the Czech Republic, the test specimens are always compacted by 2x25 impacts of the Marshall compactor which constitutes a partial modification of the US test method.

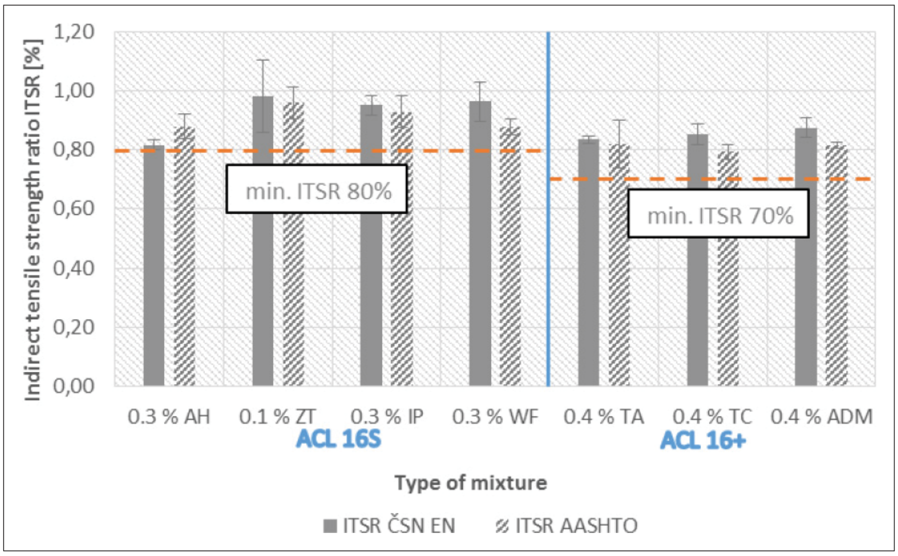

Figure 4 Results of moisture susceptibility test according to EN 12697-11 and AASHTO T283-03

By the way of example, Figure 4 summarises the resulting ITSR values according to both the Czech and US test methods. The first part of the table lists the results of asphalt mixture ACL 16S (an asphalt concrete for binder courses) with the first group of adhesion promoters on the basis of amines or amine-amides. The required indirect tensile strength rate according to CSN EN 13108-1 amounts to at least 80 % for ACL 16S. The value was achieved by all four variants of ACL 16S, while the variant with ZT, IP and WF achieved ITSR of 95 % on average. The shaded columns indicate the ITSR values determined in compliance with the modified US test method. With respect to the less favourable conditions to which the test specimens were exposed within this test method, the ITSR value decreased for all samples except the AH version although the 80 % threshold was still achieved by all mixtures.
The next part indicates the values of indirect tensile strength rates for ACL 16+ versions with new formulations of chemical surfactants on the basis of alkasilanes or unsaturated fatty acid compounds; this mixture has a permitted threshold of just 70 % ITSR. The limit was achieved in all cases; TA, TC and ADM variants also achieved ITSR of 85 % on average. With respect to the ITSR results measured for the test specimens exposed to an extra freezing cycle, the value of almost 80 % was achieved in all three mix variants.

4 Conclusion

[Normal] The adhesion between a bituminous binder and aggregate including simple adhesion test provides rapid information on the quality of particle coating by the binder and helps to exclude any aggregates which fail to form a sufficiently strong bond with the bitumen (mainly based on its hydrophilic nature). It also allows to verify the functioning of selected adhesion promoters. The results clearly indicate that rocks containing quartz or feldspar demonstrate the least ability to form a good quality bond with the bituminous binder, which is a commonly known fact, proven by many reports and research works. An insufficient degree of adhesion between the reference binder and aggregate was recorded for the following types of rock: clinkstone, granulite, granite porphyry and granodiorite. These types of aggregate also had the highest percentage of improvement in the degree of aggregate particle coating when all of the adhesion promoters were applied, relative to the reference bituminous binder with no additives whatsoever.
All of the aged binders demonstrated superior adhesion between the binder and the aggregate; in this case, hardening of the binder due to ageing improved its resistance to negative effect of water. To a certain degree, ageing is influenced by the type of aggregate used which is not always appropriate from the point of view of binder-to-aggregate adhesion. The greatest improvement occurred in the aged reference binder and amounted to roughly 10 % relative to unaged binder on average. No great improvement occurred in aged binders with adhesion promoters added; the additives applied protected the binder from negative hardening usually caused by ageing. It is obvious that the application of adhesion promoters remains effective even after the simulated long-term ageing process; this conclusion is confirmed by the findings obtained from the asphalt mixture as such; the mixtures have much less of a tendency to deteriorate in terms of water susceptibility, and they are less susceptible to stripping.
The paper has also verified the potential of new formulations of additives on the basis of alkasilanes or unsaturated fatty acid compounds, as has been confirmed by the binder-aggregate adhesion test according to the national standard CSN 73 6161. The test method demonstrated an increase in the degree of individual aggregate particle coating in comparison to the reference binder in all cases of higher doses of such adhesion promoters. The increase amounted to 20 % and even to 30 % on average in the case of granite porphyry and granodiorite, respectively. At the same time, the effects of the additives were also verified for asphalt mixture ACL 16+ (ACbin), which applied one of the less suitable aggregates (granite porphyry). However, the results need to be accompanied by further measurements, including e.g. simulated long-term ageing methods for asphalt mixtures in order to verify the effectiveness and stability of the adhesion promoters applied.

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