# Influence of Various Adhesion Promoters on Asphalt Behavior by Assessment of Water Sensitivity

J. Valentin, J. Vavřička & T. Valentová
*Department of Road Structures, Czech Technical University in Prague, Prague, Czech Republic*

ABSTRACT: Bitumen to aggregate adhesion represents one of the fundamental characteristics of asphalt mixes which are closely connected to their durability and resistance to water and frost effects. With respect to increased focus on construction cost effectiveness it is preferred to use locally available aggregate sources. These are often hydrophilic and not suitable enough to secure sufficient adhesion. Another factor is the quality of bitumen used for asphalt mixture production which bears with respect to advanced distillation processes and general business preferences of petrochemical industry another risk affecting the adhesion. Based on these assumptions different chemical adhesion promoters have been used and compared. At the same time mechanically activated microfillers based on lime and/or fly-ashes have been used as mineral adhesion promoters or intelligent substitutes to traditional filler. Asphalt mixes of $AC_{bin}16$ or $AC_{wear}11$ type have been laboratory designed with two different types of aggregates. Indirect tensile strength has been assessed for all mixes according to EN 12697-23 with determination of water sensitivity according to EN 12697-12 and by modified test procedure described by AASHTO T-283 used in the U.S..

KEY WORDS: adhesion, mineral microfillers, chemical adhesion promoters, surfactants, indirect tensile strength, water susceptibility.

## 1 IMPORTANCE OF ADHESION

As mentioned e.g. in (Hefer & Little, 2005), the term adhesion derives from the Latin “adhaerere” which means “to stick”. There are a number of definitions of adhesion; in principle, they can be divided into fundamental – expressed by the valence forces between the particle surfaces, and useful adhesion which can be described as the result of destructive types of testing. The latter basically consider both the impact of the valence forces at the interface of two substances, and the mechanical response of the components which act as either binder or filler, including any phenomena on the interface of these two substances. The type of defect can be of adhesive (disturbing the bonds between molecules of various phases) or cohesive nature (disturbing the bonds between the molecules of a single phase/substance), (Hefer & Little, 2005). The surface forces involved in the basic adhesion can be attributed to atoms and molecules in areas close to the material surface which usually behave distinctively reactively in comparison to the particles in the matter as such where there is the same power field between the individual basic particles thanks to the mutual influences of the neighbouring atoms. On the surface, the homogeneity is disturbed and the particles are usually in adverse conditions from the energy perspective, i.e. the total free energy in the system increases, which allows identifying the excess surface energy. Consequently, surface tension arises; in the case of asphalt mixtures, water attempts to infiltrate the voids between the other substances due to the gravity forces and stability levels of the individual phases (decreased mobility of atoms and molecules with possible changes of solid substance morphology).

The fact that good adhesion between the bitumen binder and aggregate forms one of the key prerequisites of necessary performance of an asphalt pavement has been known since the completion of first bitumen macadam application at the end of the 19$^{th}$ century. Besides the consistency of the bitumen binder used, the adhesiveness was researched already then. Nevertheless, more intensive research of bitumen to aggregate adhesion only started in the 1920's (Hefer & Little, 2005). Similarly to the preset main driving research force in the past was the negative impact of water infiltrating the mixture and causing defects related to particle loss and successive pothole development. The solution for the adhesion phenomenon in the field of asphalt mixtures resulted in the formation of a special "Committee on Interfacial Surface Tension", (Nicholson, 1932). The most significant finding of the 1930's was the identification of the chemical compounds which could possibly be used as an additive to improve bitumen to aggregate adhesion.

Based on the technological development in the second half of the last century, the depth of the fundamental findings concerning the relationships on the interface between the aggregate and bitumen gradually improved. However, some new problems arose which define other questions relating to asphalt mixture resistance to water – particularly the gradual implementation of the warm mix asphalt technology, where the water susceptibility parameters can deteriorate in some applications, e.g. (Kim et al., 2011; Epps & Estakhri, 2011). Analogously, this issue is known if bituminous binder and asphalt mixtures modified with crumb rubber are used to create another surface in the bitumen – aggregate system. Research has repetitively proved the experience with decreased water susceptibility (Kudrna, 2011; Valentin, 2011), based on the research, Czech technical specifications for the use of CRmB recommend applying increased quantities of lime hydrate as an additive to significantly improve the durability of the asphalt mixture.

## 2 ADHESION ASSESSMENT

With respect to over eighty years of adhesion research tradition, it is logical that a number of methods exist which can be used in adhesion quantification, or verification of the level of asphalt mix water susceptibility, thus predicting the impact on durability of the mixture. At the same time, test procedures can be divided to easily practicable tests and experimentally very precise procedures based on spectroscopy, gas chromatography or micro-calorimetry. To a certain degree, microscopic analysis of nano-indentation measurements can probably be used in the near future, too.

As mentioned by (Hefer & Little, 2011), one of the first advanced procedures utilised to describe the quality of the bitumen to aggregate bonding, or to assess the strongly or weakly adsorbing chemicals used, was extraction as commonly applied in the asphalt mixture analysis. In this context, the so-called desorption of chemical compounds has been defined, based on the effects of an extraction solvent (Petersen et al, 1974), primarily if solvents with increased polarity or concentrated effects of desorption substances are applied.

From the practical perspective, there are more appropriate methods in Europe today; EN 12697-11 specifies three harmonised test methods besides the national test procedures:

- Rolling-bottle test;
- Static tests (of coated aggregate grains in water without circulation) and
- Boiling water test.

In the Czech Republic, non-harmonised test according to ČSN 73 6161 has traditionally been used to describe the quality of bitumen to aggregate adhesion; it uses a sample of heated aggregate, 8/16 fraction, weight of 300±3 g and binder to the quantity of 12±0.3 g under a temperature defined depending on the bitumen gradation (in the case of the tests conducted, the temperature of the aggregate was 160±5°C and the bitumen temperature amounted to 170±5°C). Subsequently, after cooling the sample off in a glass vessel for one day, the sample is conditioned in water to the temperature of 60±3°C for 60 minutes. When the sample has been removed from the water, the coating of aggregate grains by the binder is assessed visually. Under ČSN 73 6161, bitumen to aggregate adhesion is evaluated using a similar system as in the case of method B under EN 12697-11:

- excellent – if >75% grains of the test sample have the A characteristic of bitumen film bond with aggregate; the characteristic may not be lower than B for the remaining grains;
- good – if >75 % grains of the test sample have the B (or better) characteristic of bitumen film bond with aggregate; the characteristic may not be lower than C in the remaining grains;
- satisfactory – if >75 % grains of the test sample have the C (or better) characteristic; the characteristic may not be lower than C in the remaining grains;
- unsatisfactory – if <75 % grains have the C characteristic.

Another example of adhesion test as used for instance in Germany is the method of measuring the contact angle which is determined as the angle between the tangent to the liquid drop surface and the interface formed by the solid substance surface. Again, there are multiple methods of applying the drop, choosing the type of the drop (bitumen, bitumen with chemical agents or a dissolved bitumen solution) in relation to this method.

Besides the aforementioned, the test method determining the proportion ratios like ITSR, under EN 12697-12 is used to assess the effects of water on asphalt mixtures and define its durability. The method uses the Marshall test specimens compacted by 2x25 blows and exposed to various application conditions from the point of view of water susceptibility; it determines indirect tensile strength for both dry and saturated specimens.

At the same time, the European test can be modified according to the American AASHTO T283 which, besides other compaction levels, also introduces specimen saturation with water as well as the application of a single freezing cycle; therefore, two negative effects – water and frost – combine. In this test, the specimens are first saturated for 10 minutes under reduced pressure; subsequently, they are located in the freezer under -18±3°C for 16 hours and then in a water bath of 60±1°C for 24 hours. Indirect tensile strength tests for all specimens are conducted under 15°C.

## 3 SPECIFICATION OF THE EXPERIMENT

Within the partial task of applied research commenced in the CIDEAS research centre which connected to some findings of the project dedicated to warm asphalt mix rheology undertaken at the Faculty of Civil Engineering, Czech Technical University in 2009-2011, adhesion tests were conducted under the aforementioned method of the ČSN73 6161 standard, using various types of aggregate and traditional bitumen 50/70. The assessments taken solely with bitumen 50/70 were used as reference. A thermal stability simulation was carried out for selected binders with chemical adhesion promoters by triple short-term ageing TFOT test (conditioning under 163°C for 15 hours).

Nowadays, the ITSR is determined for the majority of asphalt mixtures; for a number of experimental asphalt mixtures, a modified version of the test method according to AASHTO T283 has been implemented since 2011 within the CTU research. The test method modification relies primarily in the utilisation of the same test specimens as in the case of ČSN EN 12694-12.

From the point of view of used additives and chemical adhesion promoters, the measurements taken can be divided into several areas:

- Comparison of the effects of low-viscosity binders with various chemical adhesion promoters, including assessment of PPA on selected types of aggregate;
- Comparison of adhesion promoters with bitumen 50/70 and selected types of aggregate;
- Assessment of storing simulation by 3xTFOT on the changes of adhesion quality;
- Assessment of the effect of non-traditional fine-grained mineral additives of the fly ash or mechanically activated (milled) lime or dolomite.

In the following text attention is paid only to some results of the comparison of various chemical additives used as surfactants, as well as the effects of alternative mineral additives. Hydrated lime has not been included in the assessment, because its positive effect is generally well known and used in the Czech Republic. In the case of micro-ground materials, high-speed milling with mechanical and chemical activation of particles of the ground material was applied; this is based on the conversion of energy released and adjusted as a consequence of the grinding process. Mechanical activation consists of increasing the value of the substance's enthalpy (Balaz, 2008); this may consist of a certain proportion of the energy used (in some cases significantly higher than the proportion corresponding with the specific surface increase (Chodakov, 1984) during high-speed milling in disintegrators. Besides the mechanical activation effect as such, the milling might be accompanied by phase conversions of the materials treated (Pourghahramani, 2007), or by chemical reactions between the individual components of the multi-component system during or immediately after the milling process.

Additives like Addibit, Wetfix, AdHere, Iterlene and Impact by manufacturers who are nowadays involved in this field of surfactants and additives most commonly were used as the chemical adhesion promoters. In general, the substances are based on amines and polyamines (amino-polyamines, amido-amines, alkyl-amines, ethylene-amines etc.), which are usually light or dark brown and of a characteristic smell. The dosage is within 0.15 to 1.0 %-wt. of the binder; particularly the new generations of adhesion promoters are flexible and work with various quantities depending on the type of aggregate. An important perspective which has been ignored so far in the Czech Republic is the thermal stability of the additive. The generation of some fumes might be encountered during production; this is due to the vaporising of a part of the additive. This basically restricts the ultimate effect. Therefore, it is open to discussion and necessary from the point of future monitoring to pay attention not only to the improved adhesion effect but also to the stability of such effect (e.g. depending on the time and temperature during storage of bitumen binders).

Table 1: Overview of applied adhesion promoters and their content in bitumen

| Additive | Content in the bitumen | | Additive | Content in the bitumen | |
|---|---|---|---|---|---|
| | Scenario 1 | Scenario 2 | | Scenario 1 | Scenario 2 |
| FT wax | 3 % | 2 % | Addibit | 0.3 % | --- |
| AdHere (type A) | 0.3 % | 0.5 % | Iterlene (type A) | 0.3 % | --- |
| AdHere (type B) | 0.3 % | --- | Iterlene (type B) | 0.3 % | --- |
| AdHere (type C) | 0.3 % | --- | Iterlene (type C) | 0.3 % | --- |
| Impact | 0.3 % | 0.6 % | Iterlene (type D) | 0.3 % | --- |
| Wetfix | 0.3 % | --- | PPA | 1 % | --- |

Note:
For additives with more variants the particular products differs in concentration and type of effective substance. FT wax and PPA are not adhesion promoters nevertheless the impact of bituminous binders with these substances on adhesion has been assessed as well. Combination of PPA and adhesion promoter was not assessed.

From the point of view of fine-grained mineral components, a mechanically activated dolomitic lime from the Bohdaneč location was selected and the maximum grain was about 100µm. For the sake of comparing the effect on asphalt mixture susceptibility to water, filler from the Těškov quarry was applied as well. In this location, the rock consists of porphyre with light purple to greyish brown colour with multiple phenocrysts of whitish to light pink feldspar and smoky grey to brownish silica located in the macroscopically compact base mass. The rock is very hard and solid.

Last but not least, bottom ash and fly ash from fluidized combustion have been chosen. In the case of the bottom ash, the product came from the Ledvice power plant. Bottom ash is characterised by granularity corresponding with fine-grained to medium-grained sand. The apparent density of solid particles is usually ranging from 2,700 to 2,900 kg/m$^3$. The content of CaO ranges from 12 to 24 % while free CaO is usually represented to the quantity of 2 to 8 % (the main reason for selecting this material as the possible adhesion additive). On contrary, fly ash was taken from the Hodonín power plan. The fly ash is characterised by similar characteristics from the point of view of solid particles, the representation of CaO was the same as in bottom ash; however, the granularity is finer.

Six different quarries which process various types of rocks have been chosen for the test of bitumen to aggregate adhesion; the choice was made with the intention of testing representatives of aggregate with differing quality of adhesion.

Table 2: Basic characteristics of used minerals

| Quarry | Mineral type | Description |
|---|---|---|
| Markovice | amphibolite | Fine-grained metamorphic mineral, grey color |
| Chlum | clinkstone | Extrusive volcanic mineral of phorphyric origin, grey color |
| Stříbrná Skalice | amphibolite | Fine-grained metamorphic mineral, grey color |
| Svrčovec | greywacke | A type of sandstone with brownish green-grey color |
| Mladovice | migmatite | Metamorphic mineral with granite and gneissic particles, dark-grey color |

## 4 RESEARCH RESULTS

The findings of the traditional bitumen to aggregate test conducted in accordance with ČSN 73 6161 on aggregate samples of 8/16 (or 8/11) fraction, tempered under the conditions indicated in Chapter 2, are presented first. The heating-up did not exceed 2 to 3 hours. The glass vessels with aggregate coated by the bitumen binder were put in water at the temperature of 60°C after 24 hours; then they were visually evaluated. The classification was carried out by two identical evaluators. Subsequently, an average was taken of the two assessments. This partly ruled out the effect of subjective assessment by one person exclusively.

One additive to reduce viscosity of the bitumen binder, one PPA-modified bitumen binder and five chemical adhesion promoters were applied; representatives with differing proportions of effective substances were chosen for several additives. At the same time, samples with fluid fly ash were prepared; the fly ash was applied to the quantity of 0.3 %-wt of the binder.

The selected binders with adhesion promoters were further subjected to a modified process of simulated ageing with subsequent verification of the adhesion by the same manner as mentioned above.

Table 3a: Adhesion test results according to CSN 73 6161 (Markovice, Svrcovec)

| Additive | Markovice 8/16 | | | Additive | Svrčovec 8/16 | | |
|---|---|---|---|---|---|---|---|
| | Assessment according ČSN | | | | Assessment according ČSN | | |
| FT wax (2%) | B | 90% | very good | FT wax (2%) | A | 100% | excellent |
| FT wax (3%) | A | 100% | excellent | FT wax (3%) | A- | 95% | very good |
| AdHere (type A; 0.3%) | B | 90% | very good | AdHere (type A; 0.3%) | A | 100% | excellent |
| AdHere (type A; 0.5%) | A-B | 93% | very good | AdHere (type A; 0.5%) | A | 100% | excellent |
| AdHere (type B) | A- | 95% | very good | AdHere (type B) | A- | 97% | very good |
| AdHere (type C) | A- | 95% | very good | AdHere (type C) | A | 100% | excellent |
| Impact (0.3%) | B- | 87% | satisfactory | Impact (0.3%) | A- | 95% | very good |
| Impact (0.6%) | B+ | 91% | very good | Impact (0.6%) | A | 100% | excellent |
| Wetfix | A-B | 93% | very good | Wetfix | A | 100% | excellent |
| Addibit | A- | 95% | very good | Addibit | A | 100% | excellent |
| Iterlene (type A) | A-B | 93% | very good | Iterlene (type A) | A | 100% | excellent |
| Iterlene (type B) | A- | 95% | very good | Iterlene (type B) | A- | 95% | very good |
| Iterlene (type C) | B | 90% | very good | Iterlene (type C) | B | 90% | very good |
| Iterlene (type D) | A- | 95% | very good | Iterlene (type D) | A | 100% | excellent |
| PPA | B | 90% | very good | PPA | A | 100% | excellent |
| 50/70 no additive | C-D | 73% | unsatisfactory | 50/70 no additive | A-B | 93% | very good |
| Fly ash from fluidized combustion | B | 90% | very good | Fly ash from fluidized combustion | A- | 95% | very good |

Table 3b: Adhesion test results according to CSN 73 6161 (Chlum, Mladovice)

| Additive | Chlum 8/16 | | | Additive | Mladovice 8/11 | | |
|---|---|---|---|---|---|---|---|
| | Assessment according ČSN | | | | Assessment according ČSN | | |
| FT wax (2%) | B | 90% | very good | FT wax (2%) | C | 80% | satisfactory |
| FT wax (3%) | C | 80% | satisfactory | FT wax (3%) | C- | 75% | unsatisfactory |
| AdHere (type A; 0.3%) | C | 80% | satisfactory | AdHere (type A; 0.3%) | --- | --- | --- |
| AdHere (type A; 0.5%) | A-B | 93% | very good | AdHere (type A; 0.5%) | C | 80% | satisfactory |
| AdHere (type B) | C | 80% | satisfactory | AdHere (type B) | B-C | 85% | satisfactory |
| AdHere (type C) | C | 80% | satisfactory | AdHere (type C) | C | 80% | satisfactory |
| Impact (0.3%) | C- | 75% | unsatisfactory | Impact (0.3%) | B-C | | satisfactory |
| Impact (0.6%) | C+ | 83% | satisfactory | Impact (0.6%) | --- | --- | --- |
| Wetfix | C | 80% | satisfactory | Wetfix | C | 80% | satisfactory |
| Addibit | C+ | 83% | satisfactory | Addibit | D | 70% | unsatisfactory |
| Iterlene (type A) | C | 80% | satisfactory | Iterlene (type A) | C | 80% | satisfactory |
| Iterlene (type B) | C | 80% | satisfactory | Iterlene (type B) | C+ | 83% | satisfactory |
| Iterlene (type C) | C | 80% | satisfactory | Iterlene (type C) | C | 80% | satisfactory |
| Iterlene (type D) | C- | 75% | unsatisfactory | Iterlene (type D) | C- | 75% | satisfactory |
| PPA | B | 90% | very good | PPA | --- | --- | --- |
| 50/70 no additive | E | 50% | unsatisfactory | 50/70 no additive | D | 70% | unsatisfactory |
| Fly ash from fluidized combustion | C- | 75% | unsatisfactory | Fly ash from fluidized combustion | C | 80% | satisfactory |

The benefits of a number of additives are obvious from the results presented in tables 3a and 3b; at the same time, some practical experience, particularly with potential partial deterioration of adhesion when the chosen low-viscosity additive is chosen, has been confirmed. Also the positive impact of polyphosphoric acid was demonstrated. On contrary, the results of applying fly ash from fluidized combustion were not convincing; the main problem is the risk of additional hydration if the individual particles are not perfectly coated and the fly ash or aggregate grains coated in fine fly ash particles come into contact with water. In such a case, a completely non-traditional demonstration of adhesion deterioration occurs in the form of small light patches which appear in the black bitumen film.

The selected bituminous binders with adhesion promoters were then subjected to 3xTFOT simulated ageing. The adjusted procedure was chosen with respect to the prolonged effect of temperature and air. The results are given in Table 4 solely for aggregate from the Markovice and Chlum locations. As ensues from the comparison to the results of the standard adhesion test, with a prolonged effect of increased temperature most additives demonstrate adhesion deterioration which can be expressed by a loss of roughly 5 percentage points.

Table 4: Adhesion test results according to CSN 73 6161 after 3xTFOT bitumen conditioning (Markovice, Chlum)

| **Additive** | **Markovice 8/16** | | | **Additive** | **Chlum 8/16** | | |
|---|---|---|---|---|---|---|---|
| | **Assessment according ČSN** | | | | **Assessment according ČSN** | | |
| FT wax (3%) | A- | 95% | very good | FT wax (3%) | C- | 75% | satisfactory |
| AdHere (type A; 0.3%) | B | 90% | very good | AdHere (type A; 0.3%) | C | 80% | satisfactory |
| AdHere (type A; 0.5%) | A-B | 93% | very good | AdHere (type A; 0.5%) | B | 90% | very good |
| AdHere (type B) | A- | 95% | very good | AdHere (type B) | C-D | 73% | unsatisfactory |
| AdHere (type C) | A- | 95% | very good | AdHere (type C) | C | 80% | satisfactory |
| Wetfix | A-B | 93% | very good | Wetfix | C-D | 73% | unsatisfactory |
| Addibit | A- | 95% | very good | Addibit | C-D | 73% | unsatisfactory |
| Iterlene (type A) | A-B | 93% | very good | Iterlene (type A) | C- | 75% | satisfactory |
| Iterlene (type D) | A- | 95% | very good | Iterlene (type D) | C | 80% | satisfactory |
| PPA | B | 90% | very good | PPA | B-C | 85% | satisfactory |

## 4.1 Water susceptibility tests

Indirect tensile strength characteristics were determined in accordance with the methods stipulated in CSN EN 12697-12 and CSN EN 12397-23 for selected chemical adhesion promoters and, particularly, for the purposes of verifying the possibility of using mechanically activated microfiller and fluid ash for the degree of asphalt mixture water susceptibility, or for improving the durability of the asphalt mixture. At the same time, the modified test method for determining the resistance against water with a single freezing cycle according to AASHTO T283 was applied as well. Two types of asphalt mixture were chosen – $AC_{bin}$ 16+ with Markovice aggregate and $AC_{wear}$ 11+ with Chlum aggregate. This compared two types of asphalt concrete as well as the effect of two different minerals. Simultaneously, a total of eight different additives were chosen – reversible filler from the Markovice quarry, filler from the Těškov quarry, bottom and fly ash form fluidized combustion, mechanically activated dolomitic lime and selected adhesion promoters - AdHere, Iterlene and Impact. The individual additives were dosed according to the design chosen for the relevant asphalt mixture. At the same time, a reference mixture was prepared in both cases; bitumen of 50/70 penetration and standard lime filler were used. The reference mixture could be compared to the effects of individual adhesion promoters. Mineral additives were dosed straight to the asphalt mixture. In the case of chemical adhesion promoters, they were dosed first in the bitumen binder which was subsequently applied to the asphalt mixture. The following table 5 gives the results of the indirect tensile strength determination for all test specimens prepared in three different specimen conditions – dry, saturated with tempering in water and saturated with tempering in water including the completion of a freezing cycle.

As is obvious from the results presented in table 5, the use of mineral and chemical additives does not achieve the same values of indirect tensile strength in dry test specimens. In the case of modified grading curve due to increased use of fine-grained particles (fly ashes or microfillers), this is quite logical. Moreover, a rather significant negative effect of the fly ash on the ultimate indirect tensile strength characteristic is demonstrated in both cases. In contrast to that, the results of chemical adhesion promoter applications are not absolutely expectable although the differences in the strength values are not too distinctive. The ITSR ratio or the strength ratio of dry specimens and specimens exposed to water and frost cycle (hereinafter defined as ITSR2) constitute a much better characteristic for an assessment of changes in the indirect tensile strength following the prescribed effect of water, or possibly frost.

Table 5: Results of indirect tensile strength test

| Asphalt Mix | Used additive / admixture | Average ITS value (kPa) | | |
|---|---|---|---|---|
| | | dry | wet 1 | wet 2 |
| ACbin 16+ Markovice | Reference mix (no additive) | 1.89 | 1.57 | 1.53 |
| | Mechanically activated dolomite limestone | 2.01 | 1.86 | 1.80 |
| | Filter fly-ash from fluidized combustion | 0.57 | 0.30 | 0.25 |
| | Beottom-ash from fluidized combustion | 1.60 | 1.01 | 0.99 |
| | AdHere (type A) | 1.71 | 1.58 | 1.27 |
| | Addibit | 2.14 | 2.02 | 1.64 |
| | Wetfix | 1.85 | 1.56 | 1.08 |
| | Impact | 1.95 | 1.64 | 1.26 |
| | Iterlene (type A) | 2.04 | 2.18 | 1.85 |
| | Iterlene (type B) | 1.65 | 1.65 | 1.62 |
| | Iterlene (type C) | 1.58 | 1.60 | 1.54 |
| | Limestone filler + dolomite limestone | 2.10 | 2.03 | 1.45 |
| | Spilitic filler | 1.98 | 2.25 | 1.87 |
| ACwear 11+ Chlum | Reference mix (no additive) | 2.19 | 0.93 | 0.78 |
| | Mechanically activated dolomite limestone | 2.12 | 1.26 | 0.93 |
| | Filter fly-ash from fluidized combustion | 1.35 | 0.58 | 0.50 |
| | Beottom-ash from fluidized combustion | 1.47 | 0.64 | 0.58 |
| | AdHere (type A) | 2.01 | 1.25 | 1.03 |
| | Limestone filler + dolomite limestone | 2.15 | 1.30 | 0.95 |

NOTE:
water 1 – test specimens exposed to effects of water under 40°C for 72 hours
water 2 - test specimens exposed to effects of a single freezing cycle.

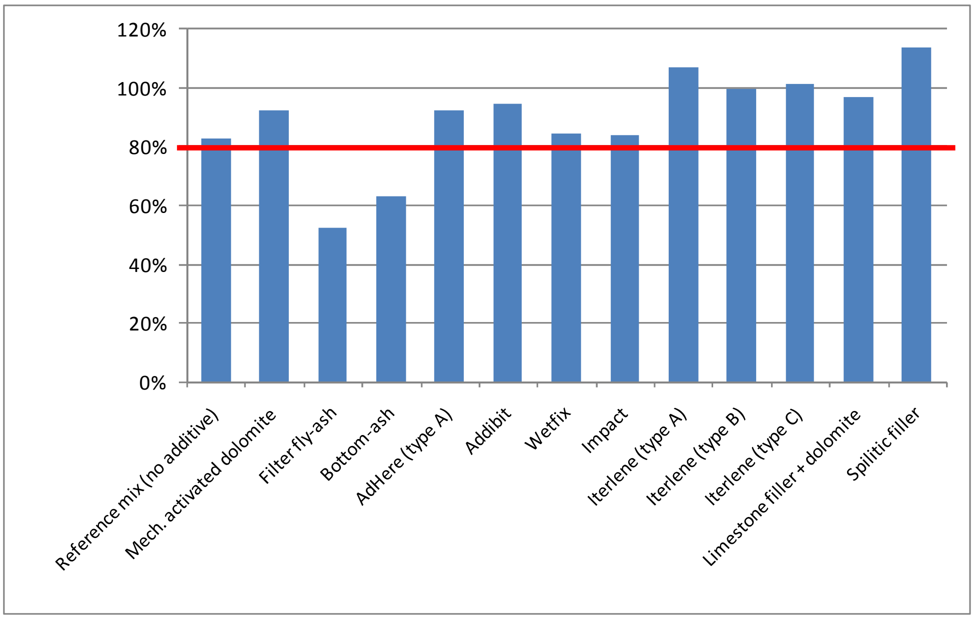


Figure 1: ITSR for mixes $AC_{bin}16+$ (with standardized threshold limit)

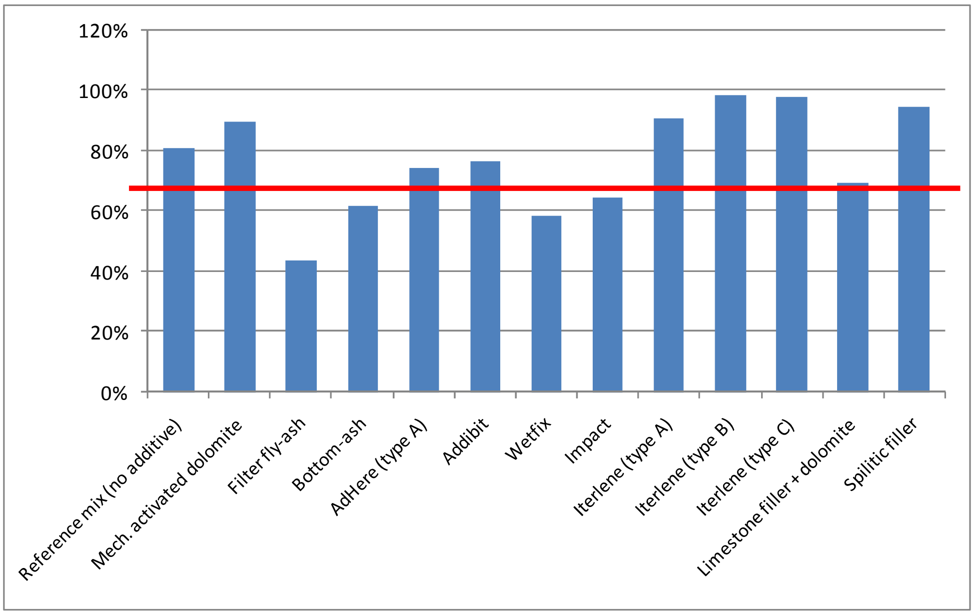

Figure 2: ITSR2 form mixes $AC_{bin}16+$ (with proposed threshold limit)

As is further obvious from the results of the ITSR values for $AC_{bin}16+$ mixtures, the mechanically activated dolomitic lime (in the form of microfiller), a suitable choice of filler as well as the majority of chemical adhesion promoters result in improved resistance against water (or the combination with a single freezing cycle). The ITSR2 values are usually lower due to the combined effect chosen. In the case of ITSR values there is a surprising result for the option with the chemical additive, Interlene (type A) and Těškov filler where the effect of water even increases tensile strength to above 100 %. In contrast to that, the negative effect of fly ash from fluidized combustion is confirmed even in this test; the indirect tensile strengths drop significantly there, too. Moreover, the occurrence of white efflorescence was observed, which can be explained by the hydrating reaction of fly ash upon contact with water despite individual grains in the mixture being coated with bituminous binder.

In the case of $AC_{wear}11+$ mix type where aggregate with generally mediocre bitumen to aggregate adhesion parameters was used the results of the alternatives compared are similar. In comparison to the $AC_{bin}16+$ mixtures, significantly lower ITSR values were achieved for all mix variants.

## 5 SUMMARY

The achieved experimental comparisons of the available chemical adhesion promoters have confirmed their expected effectiveness even in cases of aggregate with significantly deteriorated parameters of water susceptibility. In the case of comparing chemical additives, the effect of alternatives with higher proportions of effective substances is not completely apparent from presented results. In contrast, when the percentage of the adhesion promoter increases, a moderate improvement occurs in most cases. However, the aforementioned findings should be supported by measurement with binders which have been stored under higher temperatures for a certain time. This can verify the effect of the adhesion promoter substances even after a predetermined time interval, e.g. 7 days at 150-170°C. Simultaneously, it is demonstrated that mechanical activation of lime or dolomitic fillers results in further improvement of the effects of such additives to the asphalt mixture, probably thanks to the increased surface of such materials in the mixture and improved coating of the grains of the coarser aggregate fractions. It is also demonstrated that, unfortunately, the usability of fly ashes from fluidized combustion does not result in any improvement; contrastingly, the durability of the asphalt mixture deteriorates. As the fly ash is added to a hot mix and no hydration reaction takes place, a reaction with chemical compounds contained in the fly ash occurs upon first contact between the material and water. As a consequence, efflorescence forms or aggregate grains are bared in places where the fly ash particles reacted with water. These factors together then lead to weakening tensile strength characteristics and overall deterioration of asphalt mixture durability. Based on the experience gathered so far, it can be noted that fly ashes from fluidized combustion are unsuitable for application in asphalt mixtures. The possibility of using mechanically activated fly ash remains open.

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