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CHARACTERISTICS OF ASPHALT MIXES WITH FT ADDITIVE

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ABSTRACT

This article is focused on low-temperature asphalt mixture technologies using FT additive and RAP. The modern production and use of asphalt mixture technologies with reduced temperatures has many advantages. These advantages mainly help to save energy and the environment. Lower temperatures enable a reduction in energy consumption, a more acceptable working environment for workers, a reduction in negative environmental effects, such as greenhouse gas emissions, and an improvement in the workability of mixtures and a prolongation of their duration. This technology is currently becoming popular in many countries.

KEY WORDS

- warm mix asphalt (WMA),
- FT additive,
- bituminous binder,
- reclaimed asphalt pavement (RAP),
- laboratory tests.

INTRODUCTION

Warm mix asphalt was first mentioned in Europe in 1995. In 2002, through an initiative by the National Asphalt Pavement Association (NAPA), testing of these mixtures started in Europe. In the USA practical testing was undertaken under the supervision of a technical working group established by the US Department of Transportation and NAPA. The National Center for Asphalt Technology and various universities participated in this research. Subsequently, the American Association of State Highway and Transportation Officials (AASHTO) and the US Department of Transportation carried the research to Europe. The first public display was in the USA in 2004. In 2007, a team of 13 American researchers visited four European countries (Belgium, France, Germany and Norway) to collect theoretical and practical knowledge about this issue. Nowadays, warm asphalt mixtures are used in many countries such as China, Denmark, Italy, Malaysia, Russia, Sweden, Switzerland, South Africa, Great Britain, etc. [2].

A team of American researchers evaluated the information from Belgium, France, Germany and Norway and summarized them in the following points:

- Materials, production and working processes and their differences from classic asphalt mixtures (HMA),
- Resistance against permanent deformations, temperature, water, etc.,
- Traffic volume, traffic load and road classification suitable for warm mixtures,
- Option of temperature reductions,
- Advantages,
- Future of warm asphalt mixtures.

ADVANTAGES OF WARM ASPHALT MIXTURES

As was mentioned above, it is not necessary to have such a high temperature for the production of this type of asphalt mixture as in the case of hot asphalt mixtures, which result in economic and

Fig. 1 Classifications according to temperature range, temperatures, and fuel usage are approximations.

environmental advantages. Figure 1 [2] indicates the connection between the temperature and fuel amount needed for one ton of the mixture produced and the temperature scale for asphalt mixtures. Half Warm Mix Asphalt (HWMA) is the term used for a transient asphalt mixture between Cold Mix Asphalt (CMA) and mixtures produced at higher temperatures Warm Mix Asphalt (WMA), Hot Mix Asphalt (HMA) are mixtures produced at very high temperatures.

- Main advantages:
 - Lower production and working temperatures,
 - Better working conditions,
 - Advantages during paving,
 - Lower amount of emissions,
 - Reduction of fuel and lower energy costs.
- **Production and working temperatures** – by using various additives, it is possible to reduce production and working temperatures from 20 to 55 °C. Temperature reductions offer the most satisfactory conditions for laying the mixtures and also for the workers [3].
- **Working conditions** – A regulation of the European Union known as Registration, Authorisation and Restriction of Chemicals (REACH) obliges every company to register and provide information about the chemicals they use. Company staff should have a sound understanding of the chemicals they deal with, including those which can negatively impact their health. Bituminous binder is one of these chemicals. The reduction of production and working temperatures also causes reduced bituminous vapours, which is a positive aspect for working comfort. The measurement of evaporation, aerosols

and polycyclic aromatic hydrocarbons in the production of warm mixtures shows lower values than in the production of hot mixtures; they are lower than the limit values. The reduction is from 20 to 50 % [3].

- **Advantages during paving** – Among the advantages related to asphalt paving at lower temperatures include the consistency required, prolongation of the mixing time, use of a larger amount of recycled material, the possibility of compacting the mixture at a lower strength in standard conditions and the prolongation of the working time [3].
- **Amount of emissions** – The reduction of emissions depends on several factors (aggregate used, production method, reduction in temperature, reclaimed material used, aggregate moisture). On the basis of results from Belgium, France and Norway, a reduction in production emissions comes with the use of warm mixtures. This reduction is closely connected to the temperature. At a Bitumen forum conference, researchers noted that when temperatures are under 80 °C, no emissions are produced; temperatures of 150 °C result in emissions of approximately 1 mg/h, and considerably more amounts are only produced above 180 °C. The following reductions of particular chemical compounds have been recognised by the research: CO₂ (30 to 40 %), SO₂ (30 to 40 %), CO (10 to 30 %), (NO_x 60 to 70 %), volatile organic elements (50 %) and dust elements (20 to 25 %) [2], [3].
- **Fuel savings** – fuel savings from WMA due to the warming of the mixture are approximately from 11 to 35 % lower or can also be higher (up to 50 %) in the case of Low Energy Asphalt (LEA) or Low Energy Asphalt Concrete, where the aggregate is warmed to a temperature below the boiling point [2].

WMA TECHNOLOGIES

The selection of the technology depends on the reduction in temperature and the amount of the mixture desired to be produced. Warm asphalt mixture technologies can be divided into technologies using:

- Waxes and organic additives,
- Chemical additives and agents,
- Addition of water – foaming processes.
- **Technologies using waxes and organic additives** – This technology is based on reducing viscosity by heating wax over its melting point with the ensured mixing of the mixture and enabling suitable laying. The melting point should be higher than the assumed service temperatures (permanent deformations) and should minimize the brittleness of the asphalt by low

temperatures. Waxes can increase the strength of asphalt through lower penetration and a higher resistance against temperatures under and over 0 °C. The batching of the wax depends on the particular materials of the mixture input and the road classification where the mixture should be used [3], [5].

- **Addition of chemical additives and agents** – when using chemical additives there is no change in the viscosity of the bituminous binder. In this technology the ability of the surface-active additives to thoroughly coat the aggregate with the bituminous binder is utilized by the lower temperatures. The additive reduces and regulates the frictional force on the edge of the binder and aggregate by temperatures between 140 °C and 85 °C. The reduction in temperature necessary for the production and compaction of asphalt is from 20 °C to 30 °C, depending on the type of additive [3].
- **Addition of water** – This technology is based on the addition of water to the bituminous binder with the aim of foaming it to reduce the viscosity. The assumption is that the added volume will change through the atmospheric pressure into steam, by which the volume of the binder will increase and the viscosity will reduce during the short time when the mixture is cooling. Consequently, the foaming will vanish and the bituminous binder will act like a binder without any modifications.
The foaming of the binder is done directly or indirectly. With the direct foaming a small amount of water is injected into the warm asphalt binder by foaming jets to achieve a temporal increase in the binder's volume. The reduction of the temperature is between 20 °C to 30 °C. Indirect foaming is done by the use of synthetic zeolites or a moist aggregate. Zeolit is a crystallised, hydrated aluminum-silicate containing approximately 20 % of the crystalic water released by temperatures over 100 °C. Such released water causes the foaming of the binder; if the temperature does not decrease below 100 °C, it should ensure the required workability of the mixture over 6 to 7 hours. The reduction in temperature necessary for the production and compaction of the mixture is approximately 30 °C [3].

EXPERIMENTAL VERIFICATION OF THE CHARACTERISTICS OF THE BINDER AND MIXES

The experimental part of this research was focused on a laboratory verification of the asphalt mixtures' characteristics determined for sub-base pavement layers with a certain portion of the reclaimed material and asphalt mixtures where the bituminous binder is modified by a FT additive. Concretely, it is an AC 22 P; I mixture (asphalt concrete for base layer) with 5 % of RAP, the binder used was straight run bitumen 50/70 modified by the FT additive (Sasobit). The influence of various amounts of the additive on

binder characteristics and the influence of the additive and RAP on the resistance mixture against permanent deformations, resistance to fatigue and the stiffness modulus of the mixture were monitored.

EXPERIMENTAL VERIFICATION OF THE CHARACTERISTICS OF THE BITUMINOUS BINDER

The laboratory tests realised were penetration, softening point (Ring and Ball), Fraass breaking point and force ductility. In all the tests, the dependence between increasing the amount of FT additive (1, 2 and 3 %) and the comparative value (50/70) was investigated.

- softening point (Ring and Ball),
- Fraass breaking point,
- penetration at 25 °C,
- force ductility.

From the results of the penetration test (0.1 mm) and the softening point (°C), it is evident that there is a positive effect of the FT additive on these bitumen characteristics. With the increasing portion of Sasobit, there was an approximately 25 % consistent decrease in penetration, from the value 62 (0.1mm) to 46 (0.1mm). In the case of the resistance of the bituminous binder to the high temperatures, the value of the softening point increased from 52 °C to 74 °C, which means an increase of about 22 °C. In the case of the resistance of the bituminous binder to low temperatures, the additive had hardly any effect, but it also had no negative effect on

Tab. 1 *Characteristics of a bituminous binder modified by a FT additive.*

Binder	FT additive (%)	Penetration 25 °C (0,1 mm)	Softening point (°C)	Breaking point (°C)
50/70	0	61.6	52	-11
	1	52.6	57	-10
	2	49.6	63	-11
	3	46.2	74	-11

Tab. 2 *Resulting values of force ductility, 15 °C.*

FT additive (%)	15 °C			
	E _s (J/cm ²)	E ₂₀ (J/cm ²)	E ₄₀ (J/cm ²)	E ₂₀₋₄₀ (J/cm ²)
0	0.133	0.803	0.932	0.122
1	0.102	1.596	1.878	0.281
2	0.142	1.862	2.129	0.267
3	0.163	2.251	2.792	0.541

this characteristic. In all the cases the value of the breaking point was approximately $-11\text{ }^{\circ}\text{C}$. The results of the basic tests of the bituminous binder are in table 1.

The force ductility test serves to determine the strain strength of the bituminous binder. On the basis of experience, an initial temperature of $15\text{ }^{\circ}\text{C}$ was selected. The testing specimens in this test were extended to the prescribed value of 40 cm; in no case were the testing specimens trimmed [4]. The resulting values of the cohesive energy E' (J) are in table 2; the relationship between the strain (mm) and strength (N) is shown in figure 2.

CHARACTERISTICS OF THE EXPERIMENTAL VERIFICATION OF THE ASPHALT MIXTURE

The next part of this article is focused on selected laboratory tests, such as resistance against permanent deformations, resistance to fatigue and determination of the stiffness modulus.

RESISTANCE AGAINST PERMANENT DEFORMATIONS (STN EN 12697-22 + A1)

The resistance of the asphalt mixture against permanent deformations was determined using the wheel tracking test, where the passage of a vehicle on a pavement is simulated. For this test it was necessary to produce slab testing specimens. A total of 16 specimens were produced (two for each mixture). A small testing device was used, and the test was realised according to the correspondent standard, method B. From the test values of the depth of the tracked rut RD_{AIR} (mm), the comparative depth of the tracked rut PRD_{AIR} (%) and the slope of the tracked rut WTS_{AIR} (mm/ 10^3 loading cycles) were determined. The first assumption was that after the addition of the FT additive, there would be a continuous increase or decrease in the temperatures. In the case of the depth of the tracked rut of the AC 22 P; I mixture there is a course of decreasing values. In a comparison with the reference mixture, the values of the RD_{AIR} decreased from 3.5 to 1.8 mm. After the addition of the RAP into the basic mixture, there was a decrease of 2.7 mm, but in the mixtures with the modified binder, there are higher values than in the mixtures without the RAP, with a decreasing trend. The same course is also given by the values of the relative depth of the tracked rut PRD_{AIR} (%). The standard states its maximal value as 5 %. This condition was fulfilled by all the mixtures except the reference mixture with $PRD_{AIR} = 5.6\%$. In the case of the slope of the tracked rut, only the mixtures AC 22 P; I with the 3 % FT additive with a value of 0.07 mm/ 10^3 loading cycles, and the mixture AC 22 P; I + 5 % RAP

Fig. 2 Force ductility, $15\text{ }^{\circ}\text{C}$.

and 2 % FT additive with a value of 0.09 mm/ 10^3 loading cycles were satisfactory. According to the asphalt mixture datasheets [6], the maximum value for mixtures AC 22 P; I WTS_{AIR} equals 0.10 mm/ 10^3 loading cycles.

RESISTANCE TO FATIGUE (STN EN 12697-24+A1)

Fatigue can be defined as the loss of strength of an asphalt mixture as a result of repeated stress against the strength from a single load. The principle of the test is in the repeated loading of the test specimens by compression stress in the shape of the sinusoids that cause the deformation. A total of 48 testing cylindric specimens were produced: 12 for each mixture. This test was realised with the AC 22 P; I and AC 22 P; I + 3 % FT additive; AC 22 P; I + 5 % RAP and AC 22 P; I + 5 % RAP + 3 % FT additive mixtures. Each mixture was the subject of at least three levels of loading. In the described case it was a test procedure with a constant stress which had values of 800, 900 and 1,000 kPa. The fatigue characteristics of the mixture were determined from the obtained values of the loading impulses and the vertical deformation developed. The

Fig. 3 Fatigue resistance of WMA.

calculated values of the horizontal tensile deformation served to draw the fatigue envelopes and determine the regression equations from which the material constants k and n are determined. The correlation coefficient R^2 was achieved for all the mixtures except the reference mixture values, which were higher than 0.9. In the case of the reference mixture with $R^2 = 0.68$, this value shows the necessity of increasing the amount of the testing specimens. From the development of the fatigue lines it can be stated that the longest degree of serviceability can be assumed with the AC 22 P; I + RAP + FT additive mixture. This comes from the fact that with a steeper fatigue line, more cycles are needed for achieving a certain value of the strain. The shortest degree of serviceability can be assumed by the AC 22 P; I reference mixture. The development of the

fatigue line of the designed asphalt mixtures with RAP and a binder modified with FT additive are shown in figure 3.

STIFFNESS OF THE ASPHALT MIXTURES (STN EN 12697-26)

The value of the stiffness modulus S_m (MPa) can be determined by the change in the rheological characteristics of the asphalt mixture by a short time load. With the increasing value of the stiffness modulus, the resistance of the mixture against affecting the load also increased. The resistance against affecting the load depends on the stress and relative strain. The test was realised on cylindric testing

Tab. 3 Resistance against permanent deformations.

Mix	Binder	RD _{AIR} (mm)	PRD _{AIR} (%)	WTS _{AIR} (mm/10 ³ l.c.)
AC 22 P;I	50/70	3.5	5.6	0.16
	50/70 + 1 % FT additive	2.5	3.9	0.11
	50/70 + 2 % FT additive	2.3	3.5	0.11
	50/70 + 3 % FT additive	1.8	2.8	0.07
AC 22 P;I + RAP	50/70	2.7	4.3	0.13
	50/70 + 1 % FT additive	3.0	4.7	0.17
	50/70 + 2 % FT additive	2.3	3.7	0.09
	50/70 + 3 % FT additive	2.1	3.2	0.11

Tab. 4 Stiffness modulus and increase of stiffness modulus.

Mix	Temperature (°C)	S _m (MPa)	Increase of S _m (%)
AC 22 P; I	0	21499	0
AC 22 P; I + 3% FT additive		22894	6.5
AC 22 P; I + RAP		21923	2.0
AC 22 P; I + RAP + 3% FT additive		24080	12.0
AC 22 P; I	15	9318	0
AC 22 P; I + 3% FT additive		10978	17.8
AC 22 P; I + RAP		9577	2.8
AC 22 P; I + RAP + 3% FT additive		11682	25.4
AC 22 P; I	27	3049	0
AC 22 P; I + 3% FT additive		3957	29.8
AC 22 P; I + RAP		3074	0.8
AC 22 P; I + RAP + 3% FT additive		4415	44.8
AC 22 P; I	40	865	0
AC 22 P; I + 3% FT additive		1167	34.9
AC 22 P; I + RAP		873	0.9
AC 22 P; I + RAP + 3% FT additive		1329	53.6

Fig. 4 *Stiffness modulus.*

specimens by the repeated indirect tensile test (IT-CY). A total of 24 specimens were produced, 6 specimens for each mixture. This test was done on the AC 22 P; I and AC 22 P; I + 3 % FT additive; AC 22 P; I + 5 % RAP and AC 22 P; I + 5 % RAP + 3 % FT additive mixtures. As testing temperatures 0, 15, 27 and 40 °C were chosen. With the increasing temperature the values of the stiffness modules of the stated mixture decreased. By adding the RAP the

values of the modules increased minimally in comparison to the reference mixture; the higher increase can be seen in the mixture without RAP, but with the FT additive. The best improvement can be identified for the mixtures with the RAP and FT additive. For example, at 0 °C the increase of the stiffness modulus is 12 % to 24,080 MPa; at 40 °C, the increase is almost 54 % to 1,329 MPa. The resulting values of the stiffness modules with the percentage formulation of the increase in the stiffness modulus in comparison with the reference mixture are shown in table 4. The relationship between the stiffness modulus and temperature is shown in figure 4.

CONCLUSION

The production and use of asphalt mixture technologies at lower temperatures represent the future in the field of the production and use of asphalt mixtures. Technologies with lower energy demands have introduced many environmental advantages that need to be recognised. The results of various experimental assessments show improvements in the characteristics of binders modified with various additives and the parameters of asphalt mixtures with these binders. The issue of the use of RAP and its applications is in the spotlight as well.

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