THE BALTIC JOURNAL OF ROAD AND BRIDGE ENGINEERING
2022/17(2)

ISSN 1822-427X/eISSN 1822-4288
2022 Volume 17 Issue 2: 164–184
https://doi.org/10.7250/bjrbe.2022-17.564

LABORATORY EVALUATION OF THE PROPERTIES OF DENSE GRADED ASPHALT MIXTURES CONTAINING WASTE GLASS FIBRE AND CRUMB RUBBER

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Received 30 September 2021; accepted 28 January 2022

Abstract. Due to environmental issues and rising costs of construction materials, there is an increasing desire to use reclaimed asphalt pavement (RAP) material in road construction. However, using too much of this material may lead to impairment of fundamental properties of asphalt mix. Glass fibre material is a well-known modifier and could be used to compensate possible downgrade of properties. Research articles and theoretical material have shown that adding too much fibre glass reinforcement could cause damage to asphalt mixture. Therefore, in this research, reference mixture has been compared to three projected AC 11 surface mixtures with different amount of fibre glass. The same has been done to HMAC mixtures, but in this case, there is crumb rubber used as mixture modifier. Experimental part has shown that using fibre glass in asphalt mixtures for both construction layers may have positive influence on fundamental parameters of HMAC and AC asphalt mixes, which can be a good solvation for using waste glass fibre in road construction.

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Keywords: asphalt mix, asphalt production, crumb rubber, dry process, fibre glass reinforcement, HMAC, RAP.

Introduction

As the transportation infrastructure is increasingly developing, there is a need for high amount of raw material for asphalt pavement. Road structures are now subjected to significantly more traffic volume and loads, so they need to be more load-bearing, and, as a result, the rock and aggregate resources could be depleted (Ziari et al., 2019).

"Asphalt cement" refers to asphalt that has been prepared for use in HMA (hot mixed asphalt) and other paving applications. This section uses the generic term "asphalt binder" to represent the principal binding agent in HMA because "asphalt binder" includes asphalt cement as well as any material added to modify the original asphalt cement properties (Virginia Asphalt Association, 2021) (Roberts et al., 1996; Pavmeent Tools Consortium, 2021).

Dense-graded "float" in a matrix of mastic is composed of asphalt cement and screenings/fines. When properly designed and constructed, a dense-graded mix is relatively impermeable. Dense-graded mixes are generally referred by their nominal maximum aggregate size. They can further be classified as either fine-graded or coarse-graded. Fine-graded mixes have smaller and sand sized particles than coarse-graded mixes (World Highways, 2001).

Some asphalt cements require modification in order to meet specifications. Asphalt cement modification has been practiced for over 50 years but has received added attention in the past decade or so. There are numerous binder additives available on the market today. The benefits of modified asphalt cement can only be realised by a judicious selection of the modifier(s); not all modifiers are appropriate for all applications. In general, asphalt cement should be modified to achieve the following types of improvements (Roberts et al., 1996; World Highways, 2001).

High modulus asphalt concrete (HMAC) mixtures are produced using hard grade binders or modified bitumen and are known to have exceptional resistance towards rutting and fatigue. Due to the similarity between hard binder and aged reclaimed asphalt pavement binder, HMAC mixtures have great potential to incorporate higher percentage of RAP material. The hard grade binder makes HMAC mixtures highly susceptible to low temperature cracking failure (Geng et al., 2013; Rys et al., 2017). In this research, glass fibres will serve as modifier for HMAC mixtures.

Modification of the asphalt binder is one of the methods to improve pavement performance (Abtahi et al., 2009). Commonly, fibres and polymers are two most popular materials used for this purpose (Kim, 2009; Wu et al., 2008), which are also used in concrete mixes. The most popular bitumen modification technology is polymer modification (Airey, 2004; Yildrim, 2007). However, it has been claimed that among various modifiers for asphalt, fibres have received much attention for their improving effects (Hejazi, 2007).

According to research papers, glass fibres can offer a good potential for asphalt mixture modification. Glass fibres have relatively high tensile modulus (about 60 GPa) (Geng et al., 2013), an elongation of 3–4% (Rys et al., 2017) and elastic recovery of 100% (Ma et al., 2016). At high temperatures, fibres do not burn, but become soft and flexible at ~815 °C and decrease their stability at 315 °C (Miro et al., 2011). Furthermore, glass fibres are hydrophobic. Speaking about disadvantages of fibre glass, fragility and sensitivity to surface damage can be mentioned (Izaks et al., 2020). As chopped glass fibre basically is a waste product, using it in asphalt concrete mixes can positively affect the environmental situation in the world. Adding glass fibre to asphalt mixtures makes possible to gain higher strength for pavement. Specifically used glass fibre is considered a low-cost by-product. However, to make its addition economically justified, a balance must be found between the amount of fibre and the mechanical properties obtained. Too much or too little fibre will not give the desired result (VAS "Latvijas Valsts ceļi", 2021).

The use of crumb rubber to prolong the asphalt concrete life span and reduce the temperature sensitivity variation can be a good alternative to fibre glass as well. These improvements can be achieved due to the inhibitors of ultraviolet radiation effects and antioxidants contained in rubber. Using this type of modifier can also decrease the pollution level on the planet (Majoryl, 1986; Vasilie & Morozov, 2007; Hejazi et al., 2008; Esfandiarpour, 2010). Production of these types of asphalt can be separated in two methods. The first one is "dry" process, in which the crumb rubber is added to asphalt mix as a part of aggregate, while in the "wet" process, crumb rubber acts as an asphalt cement modifier (Amirkhanian, 1993). These methods can be used in the modification process using glass fibre as well.

The aim of the research is to develop typical AC and high-modulus asphalt concrete mixtures with the fundamental properties corresponding to the highest intensity class (according to the Latvian Road specifications), including local mineral materials, glass fibre and crumb rubber in the asphalt concrete composition.

To achieve the aim of the research, the following tasks have been set:

– To produce reference mixtures and research mixtures containing glass fibre and crumb rubber modifications in laboratory conditions;

- To evaluate the properties of reference and research mixtures according to LVS EN standards;
- To analyse results achieved from laboratory tests;
- To make conclusions and recommendations for further studies.

Flow chart of the research plan is presented in Figure 1.

1. Materials

1.1. Reference mixtures

The reference mixtures are projected according to all local standards to meet the requirements of the Latvian Road Specifications. The present study used AC11 surf 50/70 as a reference mixture for a surface layer and HMAC 16 20/30 reference mixture for a base layer. To prepare samples in the laboratory, all the materials were heated to a temperature

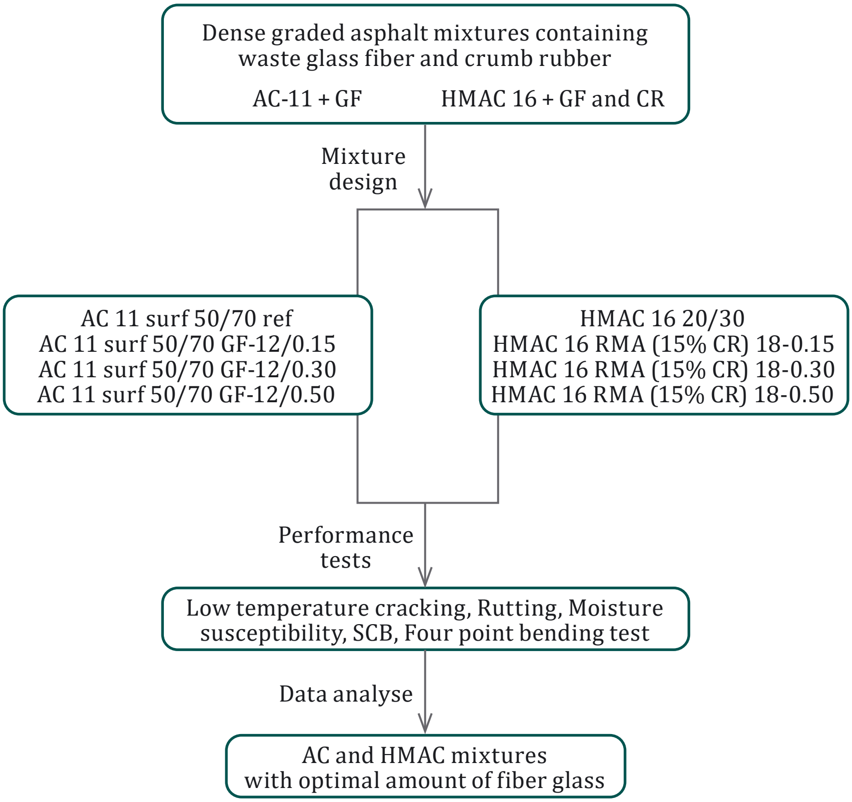

Figure 1. Flow chart of the research plan

of 150 °C in the oven. After heating, materials were then mixed for 5 min in the laboratory mixer. The Marshall samples were compacted at 145 °C using a standard impact hammer by applying a compaction effort of 50 blows on each side. The volumetric properties of each mixture were determined according to EN 12697-8. Marshall Test was conducted to determine Marshall stability and flow value following the procedure of EN 12697-34. The volumetric properties and Marshall Test results are given in Table 1. The air voids observed in Marshall specimens were used for preparing asphalt specimen slabs using roller compactor according to EN 12679-33.

1.2. Research mixtures

Three asphalt mixture samples were tested for each pavement layer. For the base layer, there was used HMAC type of mixture with adding 15% of crumb rubber and different amount of fibre glass (0.15%, 0.30% and 0.50%). For the surface layer, the authors used the reference mixture with adding same proportions of glass fibre as mentioned above. The same procedures of sample heating and mixing were performed. The volumetric properties, Marshall stability and flow tests were conducted as well. The results of evaluated tests are shown in Table 4.

Below, the authors provide the explanation of acronyms used in Table 4.

Table 1. Volumetric analysis and Marshall test results for reference mixtures

Mix	Compaction, T °C	Air Voids, %	Marshall stability, 60 °C, kN	Flow, 60 °C, mm	Bitumen content, %
HMAC 16 20/30	150±5	2.3	19.2	3.0	4.5
AC 11 surf 50/70		3.0	12.1	3.1	5.26

Table 2. Gradation table for AC 11 Surf 50/70 mixture

Sieve size, mm	<0.063	0.063	0.125	0.25	0.5	1.0	2.0	4.0	5.6	8.0	11.2	16.0
Passing, %	0	8.6	11.3	15	19.9	27.0	37.9	53.0	63.0	73.9	92.4	100.0

Table 3. Gradation table for HMAC 16 mixture

Sieve size, mm	<0.063	0.063	0.125	0.25	0.5	1.0	2.0	4.0	5.6	8.0	11.2	16.0	22.4
Passing, %	4.8	8.1	10.2	16.4	27.3	34.4	41.6	52.3	61.8	71.6	80.6	95.8	100.0

HMAC 16 RMA (15%) – 18-0.15

HMAC – Hot Mixed Asphalt Concrete;
16 – maximal size of mineral material used in the mixture;
RMA (15%) Rubber modified asphalt 15% of total mass;
18 – fibre length;
0.15 – % amount of added glass fibre.

AC11 surf 50/70 GF-12/0.15

AC11 surf – surface layer asphalt concrete with 11.2 mm maximal size of mineral material;
GF-12/0.15 – % amount of added glass fibre;
12 – fibre length;
50/70 – bitumen grade.

Glass fibre amount used in the research mixtures is from 0.15% to 0.50% of total mixture volume. Material is provided by Valmiera Glass group, which is the only local glass fibre producer. Physical properties of glass fibre used in this research are listed in Table 5.

Crumb rubber used in this study was acquired from Storimpex AsphalTec GmbH. Acquired material is pre-treated crumb rubber that can be used to modify asphalt mixes or bitumen during dry or wet processing. It creates the same properties in asphalt mixes as polymer-modified bitumen. It also improves low-temperature properties and rut

Table 4. Volumetric analysis and Marshall test results for research mixtures

	Mix	Compaction, T °C	Air Voids, %	Marshall stability, 60 °C, kN	Flow, 60 °C, mm
Base layer	HMAC 16 RMA (15%) – 18-0.15	150±5	3.5	24.4	2.8
	HMAC 16 RMA (15%) – 18-0.30		6.2	22.9	2.5
	HMAC 16 RMA (15%) – 18-0.50		7	22.8	2.6
Surface layer	AC11 surf 50/70 GF-12/0.15		2.8	13.1	3.1
	AC11 surf 50/70 GF-12/0.3		3.4	12.6	3.3
	AC11 surf 50/70 GF-12/0.5		4	10.5	2.9

Table 5. Physical properties of glass fibre

Feature	Unit	Value
Density	g/cm³	2.58
Tensile strength	MPa	3445
Compressive strength	MPa	1080
Softening temp.	°C	846

resistance of asphalt mixes modified in that manner and simultaneously lowers noise emissions. This type of crumb rubber can be used for less-frequented roads to asphalt pavements subjected to extreme loads, such as motorways or industrial areas (Additives, rejuvenators and rubber modified asphalt, 2021).

2. Methodology

The research consists of three main stages. Designing the mixture recipes according to Marshall method can be considered the first step.

The second stage consists of preparing mixtures and evaluating them for fundamental properties. Performed tests are shown in Table 6.

In the third part of this study, the received data were analysed in order to make conclusions on tested specimens' performance and find matches with the requirements of the Latvian Road specifications for further integrating of research mixtures in practical use.

2.1. Low temperature cracking

Thermal stress restrained specimen test (TSRST) was performed according to EN 12697-46 (European Committee for Standardization, 2020) to determine the low-temperature cracking performance of the mixtures. The test is conducted by keeping the length of the specimen constant and reducing the chamber temperature until the sample generates cracks due to thermal stress. The initial test temperature is 20 °C and the temperature reduction rate is 10 °C/h until failure occurs. The specimens for the test were prepared by sawing the slabs to the required dimensions (160 mm × 50 mm × 50 mm). For each mixture, two specimens were tested, and the average value was reported (Rathore et al., 2021; European Committee for Standardization, 2020).

Table 6. Performance tests for laboratory produced specimens

Test	Standard
Low temperature cracking	LVS EN 12697-46
Rutting	LVS EN 122697-22, B method
Moisture susceptibility	LVS EN 12697-12, A method
Semi-circular bend	LVS EN 12697-44
Four-point bending test	LVS EN 12697-24

2.2. Rutting (Wheel Tracking Test)

The wheel tracking test was performed to evaluate the susceptibility of the asphalt mixtures to deform under dynamic loads. As evaluation criterion, the maximum depth of the rut formed by repeated passes of a loaded wheel at a constant temperature was used (RD_{air}).

Proportional rut depth (PRD_{air}) using Equation (1):

$$PRD_{air} = \frac{RD_{air}}{\text{height of sample}} \cdot 100, \quad (1)$$

where PRD_{air} – proportional rut depth at 10 000 cycles, % and RD_{air} – rut depth at 10 000 cycles, mm.

The wheel track slope (WTS_{air}) was calculated using Equation 2:

$$WTS_{air} = \frac{(d_{10000} - d_{5000})}{5}, \quad (2)$$

where WTS_{air} – wheel track slope, mm/1000 load cycles;
d_{10000} – rut depth after 10 000 load cycles, mm;
d_{5000} – rut depth after 5000 load cycles, mm.

The wheel tracking test was conducted in dry condition according to EN 12679-22 (European Committee for Standardization, 2003a) to determine the rutting susceptibility of the mixtures. This test was conducted at 60°C by applying a load of 700 N using a rubber tire and recording the rut depth using two linear variable deformation transducers (LVDT). The test was run up to 10 000 load cycles. The results of this test indicate rut depth for a single sample tested for each mixture (Rathore et al., 2021).

2.3. Moisture susceptibility

The tensile strength ratio of bituminous mixtures indicates their resistance to moisture susceptibility and a measure of water sensitivity. Moisture damage in bituminous mixtures refers to the loss of serviceability due to water presence. Thus, higher TSR (Tensile Strength Ratio) value indicates good resistance to moisture. Respectively, the higher TSR value, the lesser the strength reduction by the water soaking condition, or the more water-resistance mixture will be (Naik, 2017).

The indirect tensile strength test was carried out to determine the effect of reduced temperature on moisture susceptibility of mixtures according to EN 12697-12 (European Commettee for Standartization, 2008). For moisture susceptibility evaluation, Marshall samples were prepared using 35 blows on each side. According to the standard, a test temperature of 5–25 °C can be used for moisture susceptibility evaluation. In this study, a test temperature of 22 °C was also the measured room temperature, and it was selected to avoid the temperature changes in the specimen during the test. The indirect tensile strength of mixtures was evaluated according to EN 12697-23 (European Committee for Standardization, 2003b). The average of three specimens is reported in the results. The ratio of the indirect tensile strength of wet specimens and dry specimens is calculated and expressed as a percentage to determine the moisture damage in the mixtures (Rathore et al., 2021).

2.4. Semi-circular bend

SCB test is used to assess the fracture toughness of asphalt mixtures. It was performed according to EN 12697-44. The test was carried out on semi-circular samples that were drilled from asphalt slab and cut to the required height of 50 mm. Semi-circular samples were then prepared by cutting 150 mm diameter cores in half and a 100 mm notch was cut at the centre of the straight edge. As defined by the standard, the test was run at a constant deformation rate of 5.0 mm/min at 0 °C until the sample broke (Zaumanis & Valters, 2020).

2.5. Four-point bending test

The higher content of high modulus binder used in asphalt mixtures makes these mixtures resistant towards fatigue cracking. However, the inclusion of high content of RA material may reduce the fatigue resistance of asphalt mixtures. To evaluate the fatigue performance resistance and acquire stiffness modulus for BBTM and HMAC mixtures, the four-point bending test was performed according to EN 12697-24 standard. To perform the test, there is a need to produce special prismatic shaped specimens made from laboratory compacted asphalt samples. This test was conducted in strain-controlled mode tests at the loading frequency of 10 Hz. The specimens were subjected to a sinusoidal loading at strain amplitude in the range of 50–400 μm/m. Before testing, all the specimens were conditioned at testing temperature for at least 2 hours and the test was conducted at 10 °C. The fatigue cycles caused microcracking of the specimen and decreased in stiffness modulus of the beam. The test was run until the stiffness modulus reached half of its initial value or until the specimen broke. Fatigue life (Nf) is defined as the number of cycles required to reach the stiffness modulus in a specimen to 50% of its initial value. The test was also run at 50 μm/m amplitude for all the mixtures until 1000 cycles to measure the stiffness modulus of asphalt mixtures as required in

SPENS2009 specifications (Rathore et al., 2021; European Comission DG Research, 2009).

3. Results and discussion

3.1. Low temperature performance

According to Road Specifications 2019 of the Latvian State Roads, in order to meet the required parameters for low temperature cracking ($TSRST_{min}$), samples for base or binder layers should perform at a temperature, which is lower than −20 °C, but for the surface layer this temperature should be below −22 °C (VAS “Latvijas Valsts ceļi”, 2020).

TSRTS critical cracking temperatures for HMAC mixture samples are shown in Figure 2. The reference has shown the best result, which is –17.5 °C. The results do not meet requirements of Road Specifications. The lowest result was shown by the sample with 15% crumb rubber and 0.50 addition of fibre glass (−9.5 °C). Adding fibre glass in amount of 0.30 from total mass can slightly improve low temperature performance, which could be optimized amount. Sample with 0.15 amount of fibre

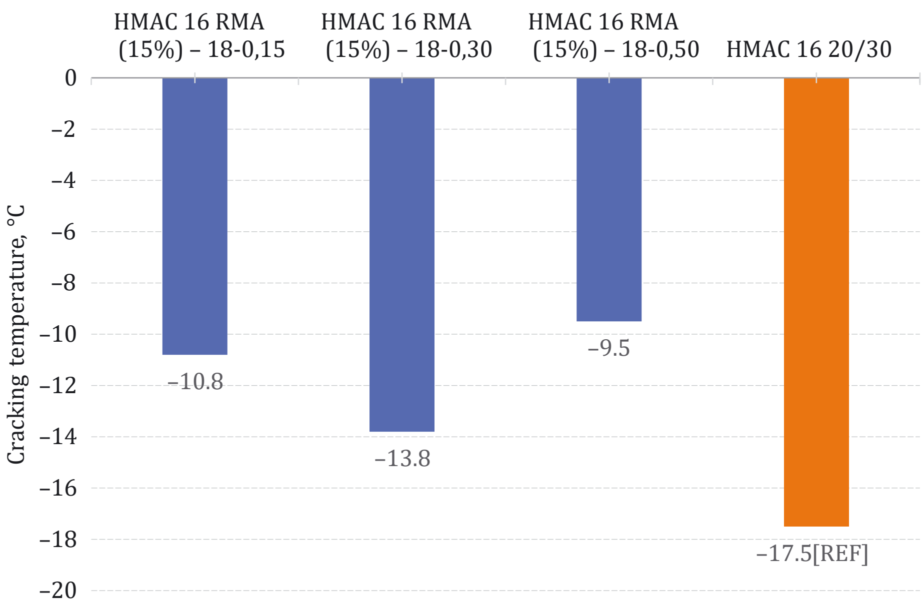

Figure 2. Low temperature cracking performance results for HMAC mixtures

glass showed weaker results compared to HMAC 16 RMA (15%) – 18-0.30. Still, it is not enough to meet the required parameters. The difference between performance of reference mix and research mixtures can be explained by different grades of binder.

Comparing AC mixtures with different amount of glass fibre, the correlation between amount of added glass fibre and reducing cracking temperature can be found. It is important to note that adding 0.15% of glass fibre improves cracking temperature by approximately 2 °C. Samples with 0.3% and 0.5% of glass fibre show reduced cracking temperature compared to the reference mixture. In this case, the recommended amount of added glass fibre should be no more than 0.15% of the total mixture mass. As the amount of fibre in the mixture increases, the thickness of the bitumen film decreases; thus, the resistance to low temperatures also decreases.

Results of cracking temperature performance tests are shown in Figure 3.

3.2. Wheel tracking test performance

Wheel tracking test results showed that all samples had very good performance against deformation. In order to meet the requirements of Road Specifications 2019 for most intensive roads in Latvia, WTS_{air} index

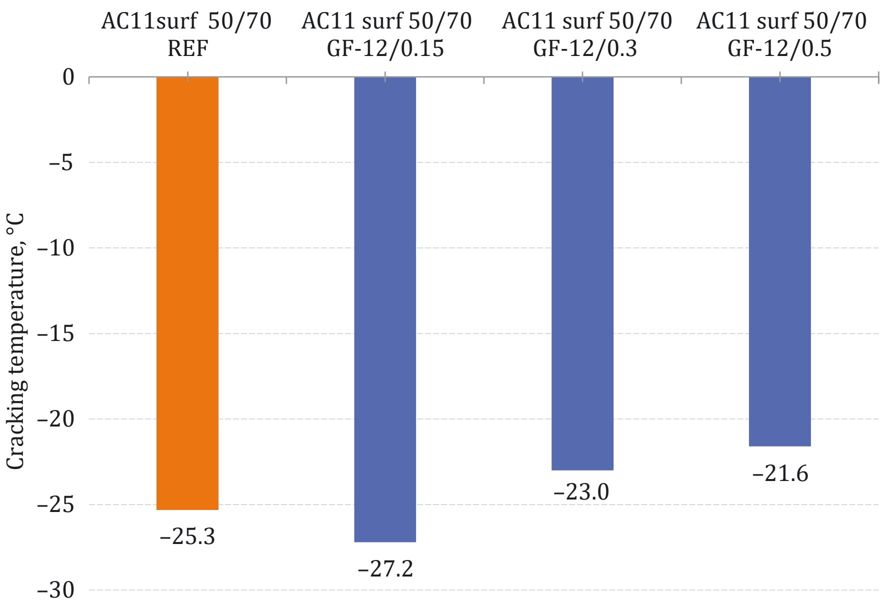

Figure 3. Low temperature cracking performance results for AC mixtures

(deformation speed mm / 1000-wheel crossing cycles) should be less than 0.1 mm/1000 cycles.

Test results varied between 0.02–0.15 mm/100 cycles for WTS_{air} and 2.3–12.4 % for PRD_{air}. All HMAC samples met the requirements of Road specifications 2019 and the parameters for most intensive road stages with intensity of AADT > 5000. All HMAC research samples showed better results than the reference mixture. The best results in this case were shown by HMAC 16 RMA (15%) – 18–0.15 sample. Adding more fibre glass slightly reduces deformation resistance for base layer samples. The same correlations can be noticed for AC11 surf mixtures. All samples showed better deformation resistance than AC11 surf 50/70. Fibre glass improves deformation resistance of asphalt mixture, but in case of surface layer samples, reference mixture and AC11 surf 50/70 GF-12/0.15 only qualify for AADT 3501-5000 intensity. Other surface layer samples showed that they met the required parameters for most intense traffic loads.

Deformation speed, proportional rail depth units and requirements are provided in Table 7.

Table 7. Compliance of wheel tracking test performance results of tested samples with road specification 2019 requirements

<table>
<tr><th rowspan="2"></th><th rowspan="2">Mix type</th><th rowspan="2">WTS_{air}, mm/1000 cycles</th><th rowspan="2">PRD_{air}, %</th><th colspan="5">Road Specification 2019 requirements</th></tr>
<tr><th>AADT <500</th><th>AADT 501-1500</th><th>AADT 1501-3500</th><th>AADT 3501-5000</th><th>AADT >5000</th></tr>
<tr><td rowspan="4">Base layer</td><td>HMAC 16 RMA (15%) – 18-0.15</td><td>0.02</td><td>2.3</td><td rowspan="8">1</td><td rowspan="8">0.8</td><td rowspan="8">0.5</td><td rowspan="8">0.3</td><td rowspan="8">0.1</td></tr>
<tr><td>HMAC 16 RMA (15%) – 18-0.30</td><td>0.05</td><td>4.8</td></tr>
<tr><td>HMAC 16 RMA (15%) – 18-0.50</td><td>0.03</td><td>4.8</td></tr>
<tr><td>HMAC 16 20/30</td><td>0.06</td><td>4.5</td></tr>
<tr><td rowspan="4">Surface layer</td><td>AC11surf 50/70</td><td>0.15</td><td>10</td></tr>
<tr><td>AC11 surf 50/70 GF-12/0.15</td><td>0.11</td><td>8.3</td></tr>
<tr><td>AC11 surf 50/70 GF-12/0.3</td><td>0.1</td><td>12.4</td></tr>
<tr><td>AC11 surf 50/70 GF-12/0.5</td><td>0.12</td><td>10.3</td></tr>
</table>

3.3. Moisture susceptibility performance

Evaluation of moisture susceptibility performance showed that all HMAC samples including reference mixture met only $ITSR_{\text{min80}}$ / 80 classification, which could be used in pavements with traffic intensity of AADT 3501-5000. HMAC 16 RMA (15%) – 18-0.50 has a slight increase in moisture susceptibility and has the best performance among HMAC specimens (88.2%). Adding less fibre glass led to significant deterioration of moisture susceptibility and HMAC 16 RMA (15%) – 18-0.15 sample showed the weakest result of 81.2%.

Moisture susceptibility performance results for HMAC mixtures are shown in Figure 4.

Received data of moisture susceptibility results for AC11 surf samples showed reversed correlation. The best results were shown by AC11 surf 50/70 GF-12/0.15 with 102.7%, which was slightly better compared to the reference mixture without fibre glass. Adding more fibre glass slightly worsened the moisture susceptibility performance. In this case, the worst results were shown by AC11 surf 50/70 GF-12/0.5 with the biggest amount of fibre glass among AC surf samples. It is important to note that, despite worsening of performance, all AC surf samples successfully met the strictest requirements of Road Specifications 2019. For most intensive road stages, moisture susceptibility should be more than 90%.

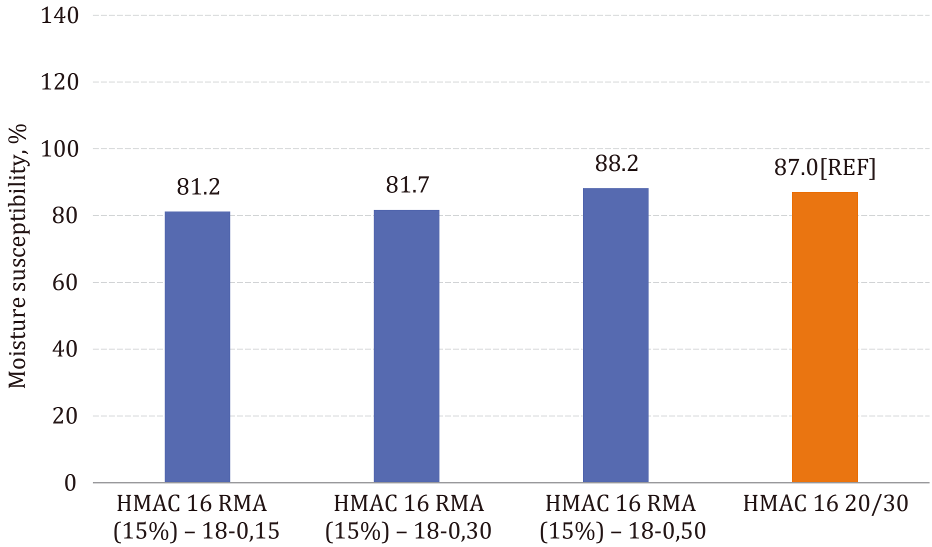

Figure 4. Moisture susceptibility performance results for HMAC mixtures

Moisture susceptibility performance results for AC mixtures are shown in Figure 5.

3.4. Semi-circular bending test performance

Fracture toughness of research and reference mixtures was determined by semi-circular bending test. There are no official statements with regard to the requirements for HMAC mixtures. Previously made studies have shown that typical fracture toughness for AC-16 mixtures used in Latvia is between 28 N/mm$^{3/2}$ for mixtures with unmodified bitumen and 43 N/mm$^{3/2}$ for PMB modified mixtures (Zaumanis & Valters, 2020). The AC-16 grading curve requirements are the same as HMAC-16; thus, it can be reasonably assumed that aggregate grading does not play a crucial role in comparing the AC and HMAC mixture fracture resistance. Adding 15% crumb rubber and 0.15% glass fibre showed a slight increase in fracture toughness index, compared to the reference mixture with hard binder. Samples with bigger amount of glass fibre (0.30% and 0.50%) showed worse performance than the reference mixture and sample with 0.15% of glass fibre. In this case, research mixture HMAC 16 RMA (15%) – 18-0.15 is the most optimal mixture comparing all three research samples to HMAC 16 20/30. It is

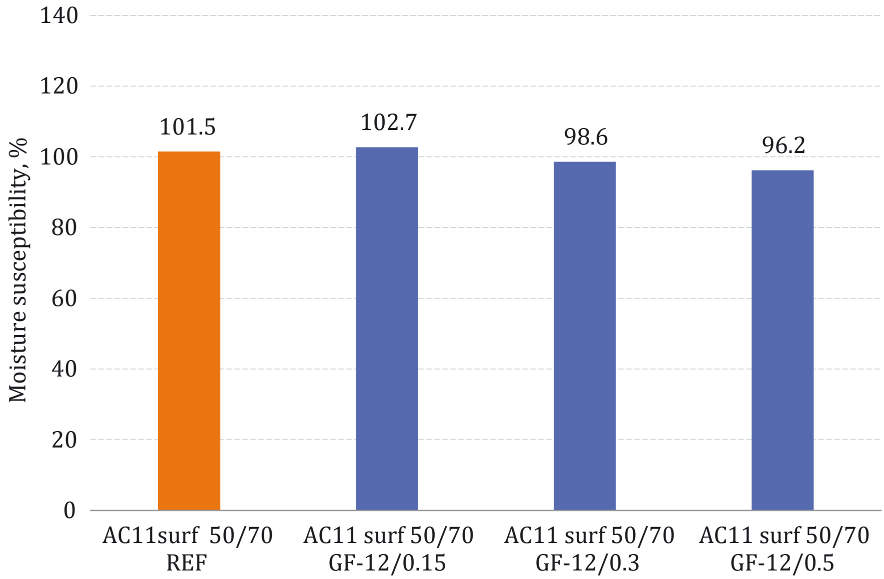

Figure 5. Moisture susceptibility performance results for HMAC mixtures

important to note that similar correlations can be noticed in moisture susceptibility performance for HMAC mixtures.

The values of fracture toughness for HMAC mixtures are shown in Figure 6.

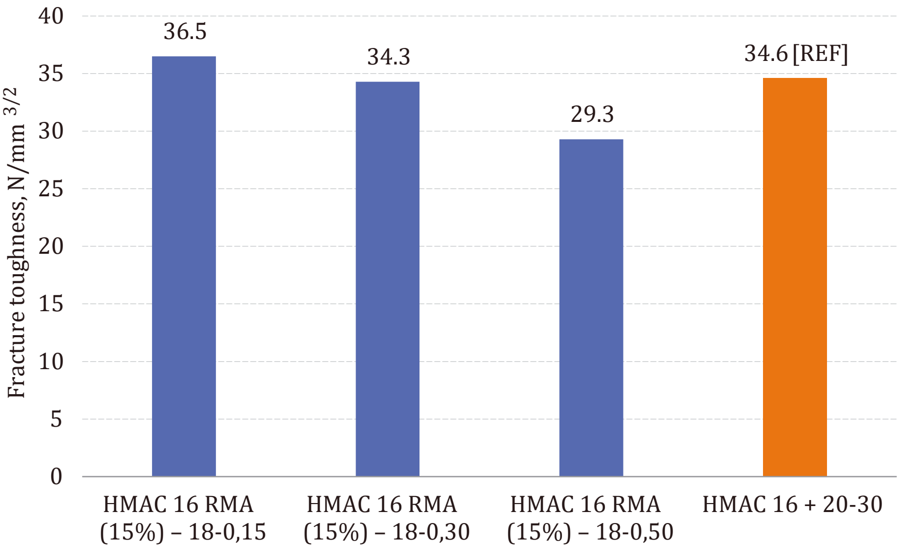

Figure 6. Semi-circular bend test results for HMAC mixtures

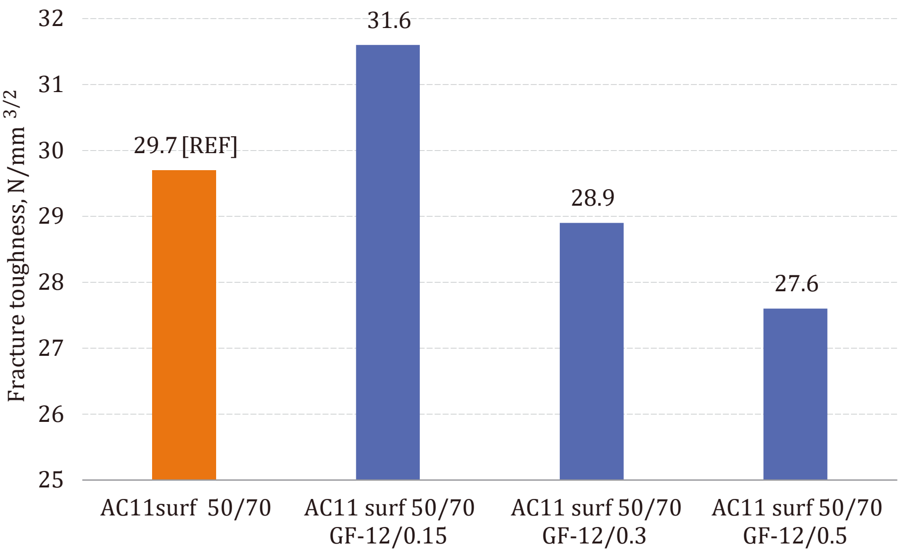

Figure 7. Semi-circular bend test results for AC mixtures

The same correlation can also be found for AC mixtures. Research mixture with 0.15% added glass fibre showed better performance than the reference mixture without glass fibre reinforcement. Samples with more added glass fibre showed worse performance than the above-mentioned mixtures. According to the acquired data, it can be concluded that adding glass fibre in amount of 0.15% from the total mixture mass can improve a fracture toughness index. Bigger amount of glass fibre in mixtures is not recommended in this case.

Results of semi-circular bending test performance for AC mixtures are shown in Figure 7.

3.5. Four-point bending test performance

Four-point bending tests for HMAC mixtures showed that the combination of crumb rubber and fibre glass in amount of 0.15% of the total mixture mass was a good compromise for improving stiffness parameter. According to the received data, adding too much fibre glass can negatively affect mixture stiffness. Reference mixture showed a better result compared to research specimens. This can be explained by the use of high-grade bitumen as a binder. Still, using lower grade of binder in combination with crumb rubber and comparatively small amount of fibre glass could demonstrate similar performance.

The obtained stiffness performance data are demonstrated in Figure 8.

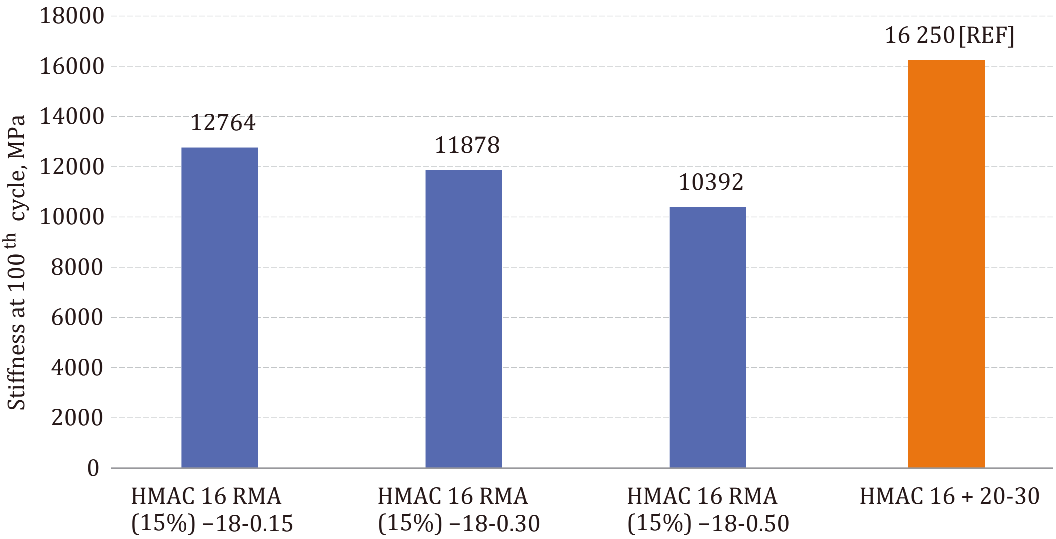

Figure 8. Stiffness modulus for the HMAC mixtures

Figure 9 contains data from computed fatigue equations, which show the strain level corresponding to 10^6 cycles (ε_6). The SPENS 2009 specification requires a minimum ε_6 value of 130 μm/m (European Comission DG Research, 2009). As it can be seen, all samples fulfilled the minimum requirements. The same correlation between amount of added fibre glass can be found in the fatigue parameter as well. Adding more fibre glass can lead to faster fatigue. HMAC 16 RMA (15%) –18-0.15 is more resistant to fatigue than other samples, especially the reference mixture with a result of 163 μm/m. HMAC 16 RMA (15%) – 18-0.50 specimen is more subjected to fatigue with a result of 149 μm/m.

Conclusions

In this study, the laboratory performance of HMAC 16 and AC 11 surf asphalt mixtures containing 15% of crumb rubber and different amount of fibre glass has been evaluated. Three mixtures for each pavement layer have been examined, tested and compared to the reference mixture. The acquired data have been analysed and based on the obtained performance data, the following conclusions have been made.

1. HMAC mixtures have not passed the cracking resistance test to meet the requirements of Road Specifications 2019. Different amount of

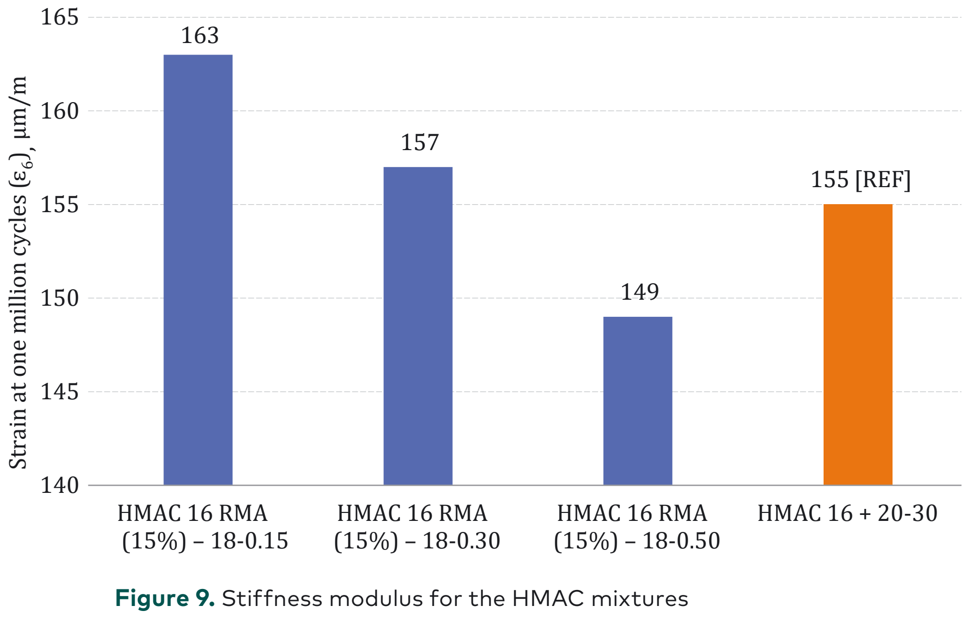

Figure 9. Stiffness modulus for the HMAC mixtures

fibre glass can affect cracking temperature performance, still no correlation has been found between the amount of added fibre glass and cracking resistance temperature. Further research is necessary. For AC type mixtures, there is a notable correlation between the amount of added fibre glass and cracking temperature. The more fibre glass is added, the lower performance is shown by samples. Still, it is important to note that adding 0.15% of fibre glass has improved cracking resistance by approximately 2 °C, compared to the reference mixture. Therefore, it is recommended to add fibre glass to AC mixture in no more than 0.15% of the total mass amount. According to the gained results, it might improve the value of cracking temperature performance.

2. Samples with 0.15% amount of fibre glass have shown better deformation resistance according to the data acquired from the wheel tracking test. Samples containing bigger amount of fibre glass show slightly weaker results. It is important to note that samples with the biggest amount of fibre glass have slightly increased deformation resistance than samples AC11 surf 50/70 GF-12/0.3 and HMAC 16 RMA (15%) – 18-0.30.
3. All the AC 11 surf mixtures have passed the minimum requirements for water sensitivity. HMAC mixtures have not passed the requirements. Still, correlation between the amount of fibre glass and moisture susceptibility can be noticed. The more mixture is reinforced with fibre glass, the more water resistant it is.
4. SCB test has shown that the optimal amount of fibre glass in both HMAC and AC mixtures should be no more than 0.15% of total mixture mass. Results have shown that adding 0.15% of fibre glass is negligible, but adding 0.5% of fibre glass could even lead to weaker SCB performance.
5. Four-point bending test has shown that for fatigue and stiffness indices a more suitable candidate is HMAC 16 RMA (15%) – 18-0.15, and samples containing more fibre glass reinforcement show weaker performance and, as a result, are less stiff and more affected by fatigue. Still, these parameters more depend on bitumen gradation.
6. Evaluated tests have shown that for AC and HMAC mixtures the optimal amount of fibre glass reinforcement could be no more than 0.15% of the total mass amount to achieve enough performance for meeting the requirements of Road Specifications 2019. Still, for HMAC mixtures some property values, such as water sensitivity, should be modified.

Acknowledgement

The authors appreciate the support provided by Latvian State Roads SJSC for the support and collaboration.

Funding

The research has been supported by the European Regional Development Fund under project [number 33], grant agreement No.1.2.1.1/18/A/007.

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