# COMBINED EFFECT OF RECLAIMED ASPHALT AND SELECTED BINDERS ON STIFFNESS AND LOW-TEMPERATURE CHARACTERISTICS OF HIGH STIFFNESS MODULUS ASPHALT CONCRETE

Kristýna Miláčková, Jan Valentin * and Petr Mondschein

Faculty of Civil Engineering CTU Prague, CZECH REPUBLIC.

*: corresponding author. Jan.valentin@fsv.cvut.cz

## ABSTRACT

*High stiffness modulus asphalt concretes (HMAC) are used as a high-performance asphalt layer with increased bearing capacity and generally improved durability. HMAC are used in binder or base courses for pavement structures exposed to high traffic loadings. Because of expected long durability this mix type should fulfill enhanced requirements on stiffness and fatigue properties. Within the research done standard HMAC mix design has been used and 30 % of aggregates have been replaced by sorted reclaimed asphalt material. At the same time a rejuvenating additive and two different viscosity improving additives have been used with standard 50/70 bitumen. For low temperature behavior characterization three test methods have been used (crack propagation test, flexural strength test on asphalt beams, relaxation behavior on asphalt beams and thermal stress restrained specimen test). Selected tests have been compared for mixes with and without RAP to identify the effect of recycled material on mix performance. The objective was to analyze behavior of each designed HMAC variant and compare with commonly recommended threshold limits. Stiffness has been assessed as well using non-destructive indirect tensile stress test.*

**Keywords: high stiffness modulus asphalt concrete, reclaimed material, stiffness, crack propagation**

## INTRODUCTION

Recycling is a current theme not only in the field of road construction. However, crucial importance of recycling and reuse of particularly natural materials can be identified in the field with respect to the considerable consumption of mostly natural (non-renewable) aggregate which is needed in large amounts for the completion of transport construction projects. In the effort to reduce the material demands of construction projects, the logical target for road pavement structures is increased proportion of recyclable material in asphalt mixes. On the other hand, if considering recycling it is always necessary to pay attention to the durability aspects of building structures which must demonstrate comparable quality and performance parameters when reclaimed materials are utilised. The importance of this perspective grows further if we focus on structural solutions which place increased demands for performance required thereof. In road construction, such construction types are binder or stabilized base pavement courses using high stiffness modulus asphalt concrete (HMAC) mixes. There are multiple possibilities to reuse the material built into the pavement and they differ by both the method of obtaining the reclaimed material and its reuse in the new mix. Further in this paper high stiffness modulus asphalt concretes are compared which differ in the presence or absence of reclaimed material while utilising various types of bituminous binders at the same time. The utilisation of HMAC achieves financial benefits, too, as it is commonly known that in case of suitable design and paving, such mixes are characterised by longer life-time and thus longer periods between completion and a need for repair or replacement.  Another saving option is also the potential of generally thinner pavement structures. In this regard, the higher resistance to fatigue and lower water susceptibility along with the possibility of designing thinner pavement structures in comparison to the traditional types of asphalt layers are added benefits from the economic perspective.

## HIGH STIFFNESS MODULUS ASPHALT CONCRETE

HMAC-type of asphalt mixes can be characterised as hot or warm mixes with composition designs which allow achieving higher stiffness values and corresponding fatigue characteristics for the mix, usually under the assumption of using bituminous binders of harder gradations or other suitable stiffening additives. The main feature of HMAC has a low air voids structure which assists in achieving higher fatigue resistance and results in a high resistance to permanent deformations with a slightly higher content of bitumen applied. This type of mix was originally developed in the 1980's in the French national laboratories LCPC *(Laboratoire Central des Ponte et Chausseé)* in collaboration with French construction companies. Its origins are associated with further research focusing on hard bituminous binders or multi-grade bitumen used in some countries. The basic idea of HMAC is based on the use of hard distilled bitumen with maximum content in the mix of 6 %-wt. which meets the fundamental performance properties like workability, increased fatigue resistance, high stiffness values and resistance to water. Use of harder binders can positively affect the stiffness of the asphalt mix and allow reduced strain transfer to the subbase with identical layer thickness as in other asphalt concrete.  The higher quantity of the binder applied improves the coherence and overall performance characteristics of the mix, [3].

According to the aggregate used, the HMAC mixes are in the Czech Republic divided into two types of grading:  0/16 and 0/22. In both cases, the preference is for use in pavements with high traffic loads, particularly if non-stabilized base layers are applied.

The main advantage of using those in the structure is minimising the occurrence of excessive permanent deformation, increased asphalt layer resistance to fatigue and improved water susceptibility. Another advantage is the option of reducing the thickness of the layer in the pavement or increasing the operation performance thereof. If the mixes are combined with use of reclaimed asphalt, a proportion of the hard bitumen component can be partially substituted on one hand; however, on the other hand, some aggregate can be replaced, too. Since HMAC mixes are not governed by technical standards on European level the specificities and required parameters always are addressed on a national level. The use of HMAC and allowed content of reclaimed asphalt in the Czech Republic is currently regulated by technical conditions TP 151 to a maximum of 25 %-wt. if the mix is applied in binder course and 30 %-wt. If applied in base course. At the same time, type testing which must be submitted if the content exceeds 10 %-wt. of reclaimed material in the asphalt mix is specified. In fact, however, the use of reclaimed materials in this type of mix is minimal with respect to the absence of a sufficient data on the performance behaviour of such structures.

## EXPERIMENTAL ASSESSMENT

Within the framework of experimental testing of possible utilisation of reclaimed asphalt material in HMAC mixes, empirical and performance-based testing was carried out for 8 different mixes. The effects of various bituminous binder types and, particularly, the effect of applying 30 %-wt. of reclaimed asphalt material for a HMAC 16 mix suitable for binder course were examined. The design and optimisation of the mix as such were carried out based on the standard procedures applied for traditional asphalt concretes according to the standard ČSN EN 13108-1. Test cylinders were usually compacted by 2x75 blows by the Marshall compactor or a gyratory compactor with vertical load of 600 kPa and revolutions depending on the bulk density required. Bituminous binder AZALT 30/45 was used for the basic reference mix used for the comparison of examined parameters. A summary of all mixes tested is given in (Cf. Tab. 1). As mixes with reclaimed material benefit from the application of rejuvenators or similar additives, variants with no reclaimed material were prepared, too. Table 2 indicates the interrelationships between the individual variants of VMT mixes which differed from each other by the bituminous binder, reclaimed material content and chemical additives used. The requirements for empirical and performance properties of HMAC mixes per se are prescribed in the industrial regulation of the Ministry of Transport of the Czech Republic, technical conditions TP 151.

*Table 1. Explanations of experimentally assessed HMAC mixes*

| |
|---|
| A - VMT16 + 4.5% 50/70 + 10% Storflux + reclaimed material (0/11) |
| B - VMT16 + 4.5% 50/70 + 0.5% Iterlow T + reclaimed material (0/11) |
| C - VMT16 + 4.5% 50/70 + reclaimed material (0/11) |
| D - VMT16 + 5.8% 50/70 + 0.5% Iterlow T |
| E - VMT16 + 5.8% 50/70 |
| F - VMT16 + 5.8% 50/70 + 3% FTP |
| G - VMT16 + 4.5% 50/70 + 3% FTP + reclaimed material (0/11) |
| REF - VMT16 + 5.8% 30/45 |

As a standard for individual variants (except for the reference mix) the initial binder was chosen to be 50/70 as the bitumen used most frequently and suitable for HMAC as well. In contrast to 30/45 binder applied in the reference mix which generally results in stiffer HMAC characteristics the choice of the 50/70 binder is also supported by the fact that one half of the mixes designed use reclaimed asphalt material where partly degraded binder of the original asphalt mix is already present and, therefore, the overall stiffness of the mix and, primarily, increased brittleness of the reclaimed material binder must be limited and sufficiently regulated. Besides Storflux which is used as a rejuvenator based on special oils, another two additives were applied which are known mostly from the field of the warm asphalt mix techniques, namely synthetic Fischer-Tropsch paraffin with the potential of lowering the manufacturing temperature of mix preparation and paving by 15-20°C, and a surfactant based on tensides under the name IterLow T. The additive is based on a different principle in comparison to FT paraffin; however, it allows reducing the working temperatures by a similar range. The reason for the application of the additives is the possibility of reducing the necessary heating of the reclaimed asphalt material while maintaining the workability needed, thus minimising further degrading of the bituminous binder contained in the material.

*Table 2. Relationships between the HMAC mix versions tested*

| Mix | Overall comparison | Effect of reclaimed material | Effect of additive |
|---|---|---|---|
| VMT A | * | | * |
| VMT B | * | *** | * |
| VMT C | * | * | * |
| VMT D | * | *** | |
| VMT E | * | * | ** |
| VMT F | * | ** | ** |
| VMT G | * | ** | |

## MIX DESIGN AND VOLUMETRIC CHARACTERISTICS

The HMAC mixes were designed in compliance with the requirements for granularity as specified by technical regulation TP 151. According to the specification, the required void content in the mix should be within the 3-6 %-vol. range while the minimum stiffness modulus value under 15°C must be 9,000 MPa. The objective of designing mixes with and without reclaimed material was making the two grading curves as close to each other as possible and eliminating thus the effects of different asphalt mix compositions. The basic compositions of aggregate mixtures are given in (Cf. Tab. 3).

*Table 3. The composition of aggregate gradations in HMAC mixes*

| Aggregate fraction | VMT mix with no reclaimed material | VMT mix with reclaimed material |
|---|---|---|
| Reclaimed material | 0 % | 30 % |
| 11/16 | 20 % | 13 % |
| 8/11 | 24 % | 30 % |
| 2/5 | 15 % | 10 % |
| 0/2 | 37 % | 15 % |
| filer | 4 % | 2 % |

The composition of the HMAC mix meets the requirements for grading curve and for the soluble binder content. The void content of the mix is affected particularly by the good aggregate shape. Based on the aggregate grading curve and shape index, it can be concluded that the shape index of the larger-fraction aggregate used is on the top limit, or even above the top limit required. Despite this conclusion, a comparison of the impact of the material added to the mix and optimisation of the mix could still be made. The reclaimed material demonstrated a better aggregate shape index which led to improved compactability and satisfactory void contents. The average void content in the mixes with no reclaimed material amounted to 5.3 %-vol.; mixes with reclaimed material reached a lower void content about 4.2 %-vol. In both cases, the values correspond with the limits restricted by 6 %-vol. for control testing (Cf. Tab. 4).

*Table 4. Fundamental empirical characteristics of HMAC 16 asphalt mixes*

| Characteristic / Mix | A | B | C | D | E | F | G | REF |
|---|---|---|---|---|---|---|---|---|
| Volumetric mass compacted (g.cm$^{-3}$) | 2.388 | 2.398 | 2.407 | 2.416 | 2.384 | 2.418 | 2.307 | 2.380 |
| Volumetric mass uncompacted (g.cm$^{-3}$) | 2.479 | 2.479 | 2.479 | 2.534 | 2.534 | 2.534 | 2.479 | 2.534 |
| Void content (%-vol.) | 3.67 | 3.27 | 2.92 | 4.67 | 5.92 | 4.58 | 6.94 | 6.08 |
| ITSR (-) | 0.87 | 0.84 | 0.81 | 0.88 | 0.85 | 0.93 | 0.84 | 1.01 |
| ITSR_frost cycle (-) | 0.79 | 0.89 | 0.94 | 0.84 | 0.74 | 0.82 | 0.72 | 0.78 |
| Elasticity modulus ratio (-) | 0.82 | 0.68 | 0.60 | 0.88 | 0.86 | 0.66 | 0.85 | 0.84 |

## STIFFNESS OF ASPHALT MIXES

In general, stiffness modulus is defined as an absolute value of the complex modulus where the value equals the creep modulus for the loading time $t=\omega^{-1}$. The value is sometimes also called the dynamic modulus as also indicated by formula 1.

$$S = \frac{\sigma_0}{\varepsilon_0} = \left| E^*(i\omega) \right| = \sqrt{{E_1}^2 + {E_2}^2} \qquad (1)$$

The aforementioned fact as stated in LUXEMBURK [1] has a crucial significance for mutual comparisons of measurement results obtained by both static and dynamic testing. The stiffness modulus definition stipulates the conditions of determination thereof at the same time; for short-term loads, it is advantageous to determine the modulus value on the basis of testing where the test specimen is strained by a harmoniously variable exciting force. For the purposes of comparison, a non-destructive test by repetitive indirect tensile stress under ČSN EN 12697-26, method F, which is usually performed on Marshall (cylindrical) test specimens has been used. The specimens do not have to be prepared by the Marshall compactor but can be prepared on a gyratory compactor, too. Direct pressure load transferred on the plane of vertical section of the sample generates tensile stress perpendicular to the direction of the load. The test uses LVDT sensors to measure horizontal deformation. The essence of the test is stressing the test specimen repetitively with a force under which the horizontal deformation of 5 to 10 microns is caused. To achieve the maximum deformation required 5 initial load pulses are applied prior to the test as such; the tester then develops the relevant load necessary to achieve the deformation. In the case of performed tests, temperatures of 5°C, 15°C, 20°C and 30°C were chosen. The temperature choices correspond to general practice used for this type of testing reaching an area where the measurement is precise enough and the variations do not significantly distort the resulting values. For thermal sensitivity result interpretation, 5°C was chosen as the minimum temperature and 30°C as the maximum temperature for VMT mixes. The value is then the ratio (Cf. Tab. 5).

*Table 5. Results of the stiffness modulus testing by IT-CY method*

| | **Temperature (°C)** | | | | **Back calculation from regression for 0°C** | **Thermal sensitivity** $t_s$ |
|---|---|---|---|---|---|---|
| **Mix** | 5 | 15 | 20 | 30 | | |
| VMT A | 8,100 | 4,500 | 2,800 | 1,100 | 9,050 | 7.36 |
| VMT B | 17,200 | 9,079 | 6,300 | 2,000 | 19,200 | 8.60 |
| VMT C | 16,650 | 11,450 | 6,900 | 2,450 | 19,500 | 6.80 |
| VMT D | 16,500 | 9,350 | 6,250 | 2,300 | 18,550 | 7.17 |
| VMT E | 12,250 | 7,400 | 5,200 | 2,400 | 13,700 | 5.10 |
| VMT F | 18,550 | 14,750 | 9,400 | 4,250 | 22,050 | 4.36 |
| VMT G | 18,950 | 14,400 | 8,750 | 3,350 | 22,600 | 5.66 |
| REF | 21,300 | 13,850 | 9,300 | 3,500 | 24,550 | 6.09 |

The reference mix (REF) with harder binder 30/45 showed a very high stiffness modulus under 15°C and met the requirement for the minimum value thereof specified in TP 151. If the reference mix is compared to mix (E) the effect of the binder applied was amply demonstrated. The mix with binder 50/70 failed to meet the stipulated value. The result is not surprising and confirms the need for utilisation of harder or modified binders in HMAC mixes. We may state that the use of reclaimed asphalt, thanks to the hard binder content of the reclaimed material, increases the stiffness modulus (C-E). This comes as no surprise as it is in full compliance with experience of binder gradation affecting the behaviour of asphalt mixes. The application of rejuvenators might reduce the stiffness modulus below the minimum value required (C-A, C-B). The highest stiffness modulus values were achieved when the additive permitting a reduction of the manufacturing temperature within the entire mix preparation and paving cycle was applied (F, G) where the values measured were higher for the reference mix, too. The experience suggests that the use of reclaimed asphalt material in HMAC mixes will not reduce the stiffness moduli; quite the contrary. However, it is necessary to monitor mix behaviour under low temperatures where the hardened binder of the reclaimed material might cause deterioration of the mix characteristics under low temperatures. From the perspective of thermal susceptibility, it is obvious that the combination of bituminous binder with IterLow T added is the least appropriate both with and without reclaimed material. On the other hand, the version with 50/70 bitumen only or with FTP additive scored most favourably. It is even obvious that besides the significantly stiffening effect, FTP has also a very good impact on a lesser decrease of stiffness under various modulus testing temperatures. The finding might be important for operation behaviour of the pavement structure where the resistance of the mix to temperature changes during the day and seasons of the year will improve.

### RESISTANCE TO CRACK PROPAGATION AND FLEXURAL STRENGTH TESTING

Resistance to crack propagation was determined in compliance with standard ČSN EN 12697-44. The resistance characteristic is determined on semi-cylindrical specimens with a crack in the centre which is loaded by flexural stress in three points to generate tensile stress in the middle of the bottom face of the specimen. The specimen is loaded by a constant 5 mm/min increment of deformation. The load is increased up to the maximum value of $F_{max}$ which relates to fracture resistance of the specimen. The tests are taken with specimens of 150 mm diameter with a 10 mm groove in the centre of the bottom edge made in advance. The test specimen is furnished with metal boosts in the location of the cylindrical supports; the characteristic dimensions of the specimen and the depth of the groove are measured. When the measurements have been taken the specimen is put in the climate chamber where it is tempered for at least 4 hours to the test temperature. The standard does not stipulate any test temperature exactly; it only mentions the most common temperature being 0°C. The mixes assessed were tested under -10°C and 0°C; only the results for the latter are presented below. The deformation $\varepsilon_{max}$ under the maximum force, maximum stress at fraction $\sigma_{max}$ which affects the bottom face of the specimen, geometric factor f(a/W) and resistance to fraction $K_{Ic}$ are determined for each specimen. The test results are given in the table 6. It is obvious that the higher the value achieved for fracture toughness the higher resistance against frost cracks will be demonstrated. Test specimens with higher values are fractured under higher forces and can transfer higher pressures. Despite the implementation of a standard method, no required results have been defined in any regulation. We may note that the content of reclaimed material in the mix increased fracture toughness measured in semi-cylindrical specimens. At the same time, it is obvious that the addition of Storflux slightly deteriorates the parameter of resistance against cracking in comparison to other specimens assessed due to softening the binder in the reclaimed material.

*Table 6. Results of crack propagation test, HMAC 16 mix, test temperature 0°C*

| Mix | Maximum load measured | Vertical shift measured | Elongation | Stress | Fracture toughness |
|---|---|---|---|---|---|
| | $F_{max,i}$ | $\Delta W_i$ | $\varepsilon_{max,i}$ | $\sigma_{max,i}$ | $K_{Ic}$ |
| | N | mm | % | N/mm$^2$ | N/mm$^{3/2}$ |
| VMT A | 10,010 | 1.4 | 1.9 | 4.70 | 27.9 |
| VMT B | 10,629 | 0.7 | 1.0 | 4.90 | 29.2 |
| VMT C | 11,628 | 0.9 | 1.2 | 5.28 | 31.4 |
| VMT D | 10,161 | 0.9 | 1.2 | 4.73 | 28.0 |
| VMT E | 9,429 | 0.7 | 0.6 | 4.30 | 25.7 |
| VMT F | 9,018 | 0.8 | 1.2 | 4.10 | 24.4 |
| VMT G | 11,303 | 0.8 | 1.0 | 5.30 | 31.4 |

The methodology of testing low-temperature properties of VMT is stipulated in TP 151. The objective is characterising the behaviour of solid mixes under zero and subzero temperatures and preventing thus the occurrence of transverse frost cracks due to simple loading of test beams 50x60x300 mm dimensions. The test of simple bending of axially loaded beams evenly by 1.25 mm/min or 50 mm/min speed is used to determine the flexural strength. Simultaneously, the relaxation test is usually taken under 0°C where the specimen is loaded by 2/3 of the maximum force at the most and then the decrease of tension is observed for 10 minutes; the time indicator of reduction to 50 % of the initial stress is determined based on that. The results of the relaxation test and flexural strength test are given in table 7. The results measured have an intrinsic logic in relation to stiffness modulus where the "softer" binder allows shorter relaxation times. The reclaimed material or bituminous binder contained in the material increase the relaxation times. The minimum requirement for compressive strength is 6 MPa which was not achieved solely by mix G.

*Table 7. Low-temperature characteristics of asphalt mixes*

| **Mix** | **Relaxation test under 0°C** | | | **Flexural strength @ 0°C (MPa)** | |
|---|---|---|---|---|---|
| | **Initial stress reduction to 50 % (s)** | **Regression parameter A** | **Regression parameter B** | **1.25 mm/min** | **50 mm/min** |
| REF | not tested | not tested | not tested | 7.62 | 7.42 |
| VMT A | 159.1 | 0.9953 | -0.0977 | 8.50 | 6.76 |
| VMT B | 348.6 | 0.9572 | -0.0781 | 8.24 | 6.71 |
| VTM C | 249.8 | 1.0184 | -0.0939 | 7.89 | 7.00 |
| VMT D | 208.8 | 1.0069 | -0.0949 | 8.08 | 6.83 |
| VMT E | 323.4 | 0.9681 | -0.0810 | 9.83 | 6.55 |
| VMT F | 1846.1 | 1.0415 | -0.0720 | 9.73 | 6.16 |
| VMT G | 364.1 | 0.9836 | -0.0820 | 5.60 | 5.18 |

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