THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

ISSN 1822-427X / eISSN 1822-4288
2015 Volume 10(4): 316–324

PERFORMANCE CHARACTERISTICS OF THE OPEN-GRADED ASPHALT CONCRETE FILLED WITH A SPECIAL CEMENT GROUT

Pavlina Cihackova[1], Petr Hyzl[2], Dusan Stehlik[3], Ondrej Dasek[4], Ovidijus Šernas[5]✉, Audrius Vaitkus[6]

[1, 2, 3, 4]*Dept of Roads, Brno University of Technology, Veveří 331/95, 602 00 Brno, Czech Republic*
[5, 6]*Road Research Institute, Vilnius Gediminas Technical University,*
Linkmenų g. 28, LT–08217 Vilnius, Lithuania
E-mails: [1]*cihackova.p@fce.vutbr.cz;* [2]*hyzl.p@fce.vutbr.cz;* [3]*stehlik.d@fce.vutbr.cz;* [4]*dasek.o@fce.vutbr.cz;*
[5]*ovidijus.sernas@vgtu.lt;* [6]*audrius.vaitkus@vgtu.lt*

Abstract. This paper presents a performance of the open-graded asphalt concrete filled with a special cement grout in the road structures, introduces practical examples of the usage of this technology and defines the main properties. In addition, laboratory design of asphalt mixtures filled with special grout is researched. Finally, the results obtained from various laboratory tests are evaluated. The paper contains the open-graded asphalt concrete filled with a special cement grout mix design procedure and results of stiffness measurement, low temperature properties, permanent deformation and skid resistance. Open-graded asphalt concrete filled with a special cement grout mixture is compared to the commonly used asphalt mixes. The open-graded asphalt concrete filled with a special cement grout showed better results than the commonly used asphalt mixes by the stiffness and resistance to the permanent deformation characteristics but behavior at the low temperatures is slightly problematic.

Keywords: asphalt skeleton, cement grout, low temperature characteristics, permanent deformation, semi-rigid layer, skid resistance, stiffness modulus.

1. Introduction

Hot mix asphalt (HMA) is commonly used material as a wearing layer for pavements of highways (or roads), streets, airports and other industrial areas. During the last decades there have been dramatic changes in traffic volumes, traffic weights and tyre pressures, which have resulted in a significant increase in a permanent deformation of hot mix asphalt pavements. Permanent deformation is a major mode of failure in flexible pavements consisting of both rutting and shoving. This problem is more common in hot climates where the stiffness of the asphalt mix is further decreased with the increase of pavement temperature (Hajj *et al.* 2011).

The occurrence of such deformations is increasing considerably during the hot period when air temperature rises up to 25–30 °C and asphalt pavement heats up to 40–50 °C (Laurinavičius, Čygas 2003).

According to various scientists, asphalt pavement rutting is affected mainly by three factors:
- the asphalt mix factor (eg aggregate gradation, binder performance grade, binder content, air void content, filler);
- load factor (eg wheel load, tire pressure, load duration, rest period, load type);
- environmental factor (eg moisture, temperature, ageing).

Extensive research has been conducted to evaluate the influence of these factors on the performance of pavement structure (Breakah *et al.* 2011; Collop, Elliot 1999; Ding *et al.* 2011; Liu, Wang 2003). However, there still remains many problems with the performance of durable pavements. Traffic loading, which directly affects the asphalt pavement and structure, is the most studied and analysed factor. However, it is important to note, that asphalt pavement deteriorate even if there are no traffic at all. This is due to the irreversible physical and chemical processes that change in time, and asphalt pavement surface is also affected by environmental factors such as temperature variations, amount of rainfall and amount of water in soil.

The asphalt pavement is subjected to many distresses during its service life. Recently, rutting in asphalt pavements has become one of the major distress forms with the increase in traffic volume, tyre pressure and axial load.

doi:10.3846/bjrbe.2015.40

http://www.bjrbe.vgtu.lt

Depending on the magnitude of the traffic loading and the relative strength of the pavement layers, rutting occur in the asphalt wearing layer, base or subgrade layer or in a combination of these layers (Tarefder *et al.* 2003). It often happens within the first few years after opening to traffic. The rut is formed because of the shear stress in asphalt layer which causes large plastic deformations, thus the part of the asphalt layer is imprinted into the ridge at the edges of wheel roll zone (Oscarsson 2011; Xu, Huang 2012).

The rutting behaviour of asphalt mix depends not only on the properties of aggregate and binder but also on how they interact with each other in a mixture. There are occasions when binders (eg very stiff binder) and aggregate (eg aggregate with 100% fractured surface) are adequate, but the mixture fails to exhibit low rutting because of other properties (such as incorrect air voids and binder content). Mixture properties alone are not sufficient to ensure low rut because they vary with repeated traffic loads, temperature and moisture etc (Tarefder *et al.* 2003).

The temperature is one of the most important environmental factors, which affects the stiffness of asphalt pavement. Low temperature cracking is one of the major distresses in asphalt pavements. Cracking is a serious problem in cold regions as well as in areas with large daily temperature fluctuation. Whenever the ambient air temperature drops, the bitumen tends to contract. This continuous contraction phenomenon results in a tensile thermal stress build-up in the mixture. If this thermally induced stress exceeds the tensile strength of the asphalt pavement, a transverse crack will occur at the surface. This thermal cracking develops at a critically low temperature, referred to as the fracture temperature (Bhasin, Motamed 2011; Bražiūnas *et al.* 2013; Kanerva *et al.* 1994). Also due to the rise in surface temperature over the temperature of bitumen softening point the bitumen softens and causes formation of waves, inflows and ruts.

The problem of rutting has been relevant and yet unresolved in Lithuania as well as in other countries. Ruts become deeper as heavy vehicles drive on highways and other country roads. With no timely corrections to the pavement in a few years rutting would exceed the limit depth of 20 mm and reach a critical depth of 40 mm, what would inevitably increase the number of traffic accidents (Sivilevičius, Vansauskas 2013).

According to Lenfant (2012), there are several ways to solve rutting problem:

– to use a harder binder grade,
– to reduce the thickness of wearing courses,
– to increase stiffness modulus,
– to use a high penetration index binder,
– a higher quality of aggregates in asphalt mixes.

Generally, pavement structures are divided into two groups: flexible and rigid. While flexible asphalt pavement stiffness depends heavily on the temperature, the temperature has no effect on rigid concrete pavements. Asphalt pavements consist of several relatively thin asphalt layers, which are connected and interact with each other. They are laid on the base layer, which lies on the subgrade. Loads from traffic are distributed through all the layers from the surface to the subgrade and by approximately triangular spreading of forces. Concrete pavements consist of concrete slabs and base layers which lie on the subgrade. The layer has a thickness of approximately 200 mm to 300 mm (depending on traffic load) and it is necessary to use longitudinal and construction joints reinforced with dowels and tie bars. The advantages and disadvantages of the flexible and rigid pavements are given in Table 1.

Semi-rigid or semi-flexible pavements was developed in France in early 1960's as a cost effective alternative to Portland cement concrete pavement (Gawedzinki 2008). This type of pavement has the advantages of the both parts: performs like concrete and is flexible like asphalt mixtures. As the construction of grouted macadam has developed, so have the applications. Today it is used for bus stations, port pavements, industrial and warehouse floors, airport platforms, taxiways and runways, brake and acceleration strips at traffic lights and bridge deck overlays (Al-Qadi *et al.* 1994; Oliveira *et al.* 2006; Van de Ven, Molenaar 2004).

Semi-rigid pavements due to high performance have become the prevailing structure type of base layers used on major highways in China (Sun 2007; Zhuang *et al.* 2003). Vaitkus and Paliukaitė (2013) determined that after 5 years of road exploitation the rut depth of open graded asphalt filed with cement grout is the lowest one of the tested 27 different pavement structures. Anderton (2000) made an inventory of four USA Air Force facilities where grouted macadam had been used. The overall condition of these sites was very good. The city of Stockholm has been using grouted macadam at bus stops since 2001. Most of them needed no maintenance.

Mississippi Dept of Transportation performed a project investigating grouted macadam at two signalized,

Table 1. The advantages and disadvantages of flexible and rigid pavements

Advantages		Disadvantages	
Flexible pavement	Rigid pavement	Flexible pavement	Rigid pavement
Designing, constructing and repairing is easier; Easily recycled; Produce less noise; Do not require any longitudinal or transverse joints.	Ability to use without any repairs; High durability and lightness of the surface; More resistant to loads from heavy trucks.	Black surface; The possibility of properties changing during usage period; Sensitivity to high/low temperatures and high static loads.	The base course must be of a higher quality; Difficult repairs and recycling; Higher initial costs.

heavily trafficked intersections (Battey, Whittington 2007). The project included construction, testing and a five-year performance evaluation. In the performance evaluation the grouted macadam was the only pavement material that had no rutting. It was also otherwise in a good condition but there were some problems with skid resistance.

Jacobsen (2012) concluded that grouted macadam has mechanical properties similar to those of asphalt concrete, the difference is that it is stronger, stiffer and not prone to rutting. Thus it is considered suitable as a pavement material alternative for intersections experiencing problems with severe rutting. The downside of this material is that it is expensive and takes more time and precision to construct compared to asphalt concrete and that a special license is often required.

From the analysis of the experience of semi flexible asphalt pavement with a special cement grout, it is necessary to further develop this technology. The aim of this paper is to evaluate the determined characteristics of designed open-graded asphalt concrete filled with a special cement grout (AC o-g CG) and compare to common asphalt mixes.

2. The concept of a semi-rigid layer

A semi-rigid layer consists of two major components, which are the open-graded asphalt according to the standard *EN 13108-7:2006* and *EN 13108-7:2006/AC:2008 Bituminous Mixtures – Material Specifications – Part 7: Porous Asphalt*, and the high-performance polymer-modified cement mortar grouting material. The basic property of open-graded asphalt is air void content. Air void content of open-graded asphalt mix must be between 25% and 30% of air voids by volume (Marshall Mix Design method). The recommended components and their composition of the open-graded asphalt are given in Table 2 based on EucoDensit *Densiphalt Handbook* of 2004 and Wu and Zhang (2011).

Cement mortar, which is poured into the open-graded asphalt skeleton, consists of cement, fine aggregates, water and plasticizers. Examples of suitable concrete super plasticizers as naphthalene-based, melamine-based, vinyl-based, acrylic-based and carboxylic-based products are given in Densit Patent *No. WO2002075052 A1* of 2002. The critical factors in the design of modified cement mortar are the flow time and compressive/flexural strength. The Czech standard ČSN 73 *6127-3:2008 Stavba Vozovek – Prolévané Vrstvy – Část 3: Asfaltocementový Beton* [Road Building – Grouted Courses – Part 3: Open-Graded Asphalt Concrete Filled with a Special Cement Grout] specifies the requirements for cement mortar strength during compression (at least 25 MPa after 28 days) and for flexural strength (at least 4 MPa after 28 days).

Table 2. The recommended components and composition of the open-graded asphalt concrete

Component	Percentage by weight
Bitumen	from 3.6 to 4.6
Limestone filler	4.0
Cellulose fibers	0.2
Crushed aggregates	from 91.2 to 92.2

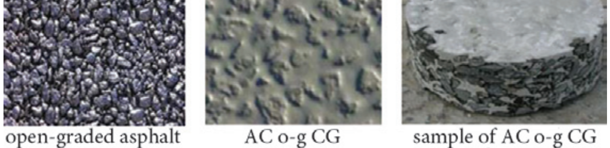

Fig. 1. Semi-rigid layer

The German document of Road and Transportation Research Association (FGSV) *M HD – Merkblatt für die Herstellung von Halbstarren Deckschichten* [Technical Rules for Production of the Semi-Rigid Pavements] of 2010 contains samples of pavement structures using AC o-g CG. Choice of binder type is also prescribed (50/70, 70/100 and PMB 25/55-55). Content of fibers is at least 0.2%. The quality of cement mortar is controlled visually as in Czech requirements. Taking into account the functional characteristics, AC o-g CG has usually higher values of stiffness modulus compared to conventional asphalt mixtures.

This type of layers is used in parking areas, bus stops, airport runways, terminals, or areas ahead of crossroads, where they effectively prevent formation of permanent deformations. Furthermore, the layer is also used in container depots, port trans-shipments and in industrial storage areas, where it is possible to take the advantage of its resistance against local puncture loads. They are also used on surfaces of petrol stations and oil depots, where the subgrade or soil is not polluted due to impermeability of the layer. Semi-rigid layers are capable of resisting the effects of chemical defrosting substances and are resistant even to large variations in temperature. Due to fast strengthening, it is possible to put the surfaces into operation already after 12–24 h.

AC o-g CG is a semi-flexible wearing course composed of a flexible asphalt mixture with a gradation up to 8 mm or 11 mm and grouted mortar. The semi-flexible properties are achieved by filling the open-graded asphalt mixture (air void content between 25% and 30%) with a self-levelling grouted mortar. After mixing, mortar is spread evenly or pumped on to the open-graded asphalt and spread evenly by using a rubber scrapers and thereby penetrates into the voids without requiring vibration. The mortar is applied only on the cooled down open-graded asphalt mixture. Usual dosage of mortar is 10 l/m^2–15 l/m^2 at 50 mm thickness of AC o-g CG layer.

In the Czech Republic, this technology is fully approved and a valid standard Č*SN 73 6127-3:2008* exists since 2008. Semi-rigid layer is now used quite commonly, eg in many industrial areas and on bus stops in Prague. In Lithuania, semi-rigid pavements have started being used in 1999. Since then this pavement type was laid on the Vilnius International Airport, on bus stops, roundabouts, and in 2007 also on the experimental pavement structure road in the Vilnius City (Vaitkus *et al.* 2012). An example of a semi-rigid layer is shown in Fig. 1.

3. Experimental research

3.1. Design of asphalt mixtures

Asphalt mixture forms the supporting skeleton of a semi-rigid layer. The standard *ČSN 73 6127-3:2008* requires that the void content is between 17% and 32% and that the binder drainage does not exceed 0.3%. The resulting composition of the asphalt mixture is given in Table 3.

The temperatures of the asphalt mixture were chosen according to the standard *EN 12697-35:2004+A1:2007 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 35: Laboratory Mixing*. The temperature of mixing was 160 °C and the temperature of compaction – 150 °C.

The air void content of the designed mixtures was determined according to the standard *EN 12697-8:2003 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 8: Determination of Void Characteristics of Bituminous Specimens* and the final value was calculated as 27.9%, which complies with the standard requirements.

The second requirement to the asphalt mixture is binder drainage, which was determined by Schellenberg's method incorporated in the standard *EN 12697-18:2004 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 18: Binder Drainage*. The resulting value was 0.10%, fulfilling the second condition of the standard.

3.2. Design of filling grout

Filling grout forms an essential part of semi-rigid layers and has a significant effect on its major properties. It is therefore important to pay close attention to its design and to find a suitable composition. The accuracy of the composition was assessed using the Marshall specimens. After cutting, the quality of the filling of gaps was inspected visually. The initial composition was determined experimentally and gradually improved until reaching the final version given in Table 4.

Czech standard *ČSN 73 6127-3:2008* specifies the requirements of filling grout compression (at least 25 MPa) and flexural strength (at least 4 MPa). To verify that both parameters are within the standard requirements, two sets of the test specimens of grout final composition were made. The first specimen strength was determined after 7 days and the second – after 28 days. The test was carried out according to the standard *EN 196-1:2005 Methods of Testing Cement – Part 1: Determination of Strength*, which specifies the specifications of the compressive and flexural strength determination test with specimens, dimensions of which are 40×40×160 mm.

The results of the final composition filling grout strength after 28 days were very promising and with sufficient margins. The determined value of compressive strength was 29.9 MPa and the flexural strength – 8.7 MPa. This composition of filling grout was used for further tests.

3.3. Methods of the experimental research

The research scheme of AC o-g CG and common asphalt mixtures characteristics is shown in Fig. 2.

Mechanical properties of the AC o-g CG, which were carried out during the research are given in Table 5. All laboratory tests were performed in road laboratory of Brno University of Technology. For the purposes of the stiffness modulus comparison, five trapezoidal shaped specimens were produced from each mixture. Each measured value of low temperature characteristics is an average of the results from five measurements (five test specimens).

For all tests of the AC o-g CG the test slabs were made. Specimens of stiffness modulus and low temperatures characteristics determination test were cut using a circular saw with a diamond blade.

Table 3. Composition of porous asphalt mixture

Component	Percentage by weight	Recommended % by weight[1]
Aggregate fraction 8/11	91.9	from 91.2 to 92.2
Limestone filler	3.3	4.0
Bituminous binder 50/70	4.5	from 3.6 to 4.6
Fibers TOPCEL	0.3	0.2
Total	100.0	100.0

Note: [1] – these quantities are recommended by EucoDensit *Densiphalt Handbook* of 2004 and Wu and Zhang (2011).

Table 4. Composition of filling grout

Component	% by weight
Sand fraction 0.063/0.5	20.4
Limestone filler	20.4
Cement	40.8
Water	8.2
Superplastificiser *Soicrat*	10.2
Total	100.0

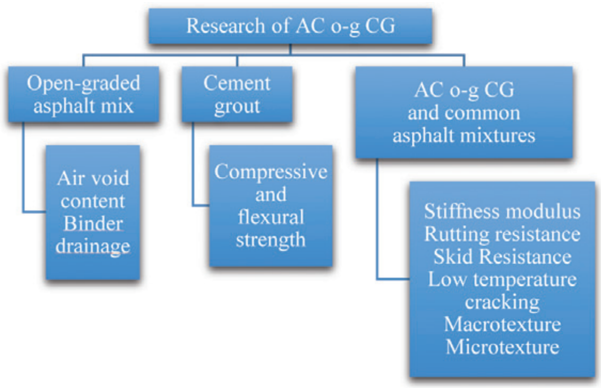

Fig. 2. The research scheme of AC o-g CG and common asphalt mixtures characteristics

Table 5. Methods of the experimental research

Property	Test method by the European standard
Stiffness modulus	*EN 12697-26:2012 Bituminous Mixtures. Test Methods for Hot Mix Asphalt – Part 26: Stiffness (Two Point Bending Test on Trapezoidal Specimens, 15* °C, 5–25 *Hz)*
Low temperature characteristics	*EN 12697-46:2012 Bituminous Mixtures. Test Methods for Hot Mix Asphalt – Part 46: Low Temperature Cracking and Properties by Uniaxial Tension Tests (Thermal Stress Restrained Specimen Test)*
Wheel tracking test	*EN 12697-22:2003+A1:2007 Bituminous Mixtures. Test Methods for Hot Mix Asphalt – Part 2: Wheel Tracking (Small Size Device on the Air, 50* °C)
Skid resistance:	
Macrotexture	*EN 13036-1:2010 Road and Airfield Surface Characteristics. Test Methods – Part 1: Measurement of Pavement Surface Macrotexture Depth Using a Volumetric Patch Technique*
Microtexture	*EN 13036-4:2011 Road and Airfield Surface Characteristics. Test Methods – Part 4: Method for Measurement of Slip/Skid Resistance of a Surface: The Pendulum Test*

4. Analysis of the experimental research

4.1. Stiffness modulus

Measurements of the stiffness modulus were performed on five test specimens, which were made from AC o-g CG. The test temperature was 15 °C and loading frequencies varied from 5 Hz to 25 Hz. According to Uddin (2003) the natural frequency of the pavement oscillation is between 6–12 Hz. The design value was set in accordance with Czech Technical Guidelines *TP 170 Navrhování vozovek pozemních komunikací* [Pavement Design] to 15 °C and frequency of loading – to 10 Hz. The test results are presented in Fig. 3.

The test results showed, that the stiffness modulus of the AC o-g CG at the range of natural pavement condition is 7980 MPa. This value complies with the requirements of the asphalt mixture stiffness modulus according to the Czech National Annex (Performance Approach) of the standard *EN 13108-1:2006*. In comparison with other mixtures, which are commonly used in the Czech Republic in urban areas for wearing courses and binder courses, the stiffness modulus of the AC o-g CG is the highest at all frequencies.

The relationship between stiffness modulus of the AC o-g CG and temperature is presented in Fig. 4. For the purpose of more extensive evaluation of the mixtures, selected parameters of the common asphalt mixtures with different binders are also included in Fig. 4.

Stiffness modulus of AC o-g CG at 40 °C was 4012 MPa and it was the highest of all compared mixtures. Fig. 3 shows that the AC o-g CG does not exhibit such a high temperature influence as in the case of asphalt mixtures. This is due to the presence of the cement mortar. Such property is advantageous especially at the higher temperatures when the AC o-g CG exhibits high stiffness and therefore the lowest tendency towards formation of the permanent deformations (rutting).

4.2. Low temperature cracking and properties by Thermal Stress Restrained Specimen Test

Table 6 shows a comparison of low temperature characteristics of the AC o-g CG and the selected commonly used asphalt mixtures with different binders.

The Thermal Stress Restrained Specimen Test showed that AC o-g CG temperature of failure (frost crack) was –11.2 °C. In comparison with other types of asphalt mixtures, the temperature of failure was 36% higher than the average of all mixtures. The highest stress at failure was 5.03 MPa lower than the average of all compared mixtures. Probably a low resistance to frost is caused by low stress relaxation of cement grout in low temperatures.

4.3. Wheel tracking test

The wheel tracking tests were performed according to the standard *EN 12697-22:2003+A1:2007* at 50 °C temperature using small device (air conditioning). Two parameters were evaluated according to the standard:

WTS_{AIR} = the increment of the rut depth, which is calculated as an average value at which the rut depth increases as a result of repeated movement of loading wheel in a small test device, in mm/10^3 cycles.

PRD_{AIR} = relative depth of the rut of the tested asphalt mixtures after N load cycles in a small test device, in %.

The results of the AC o-g CG wheel tracking test and a comparison with the requirements of the standard valid in the Czech Republic are given in Table 7. The measured value is an average of the results determined on two slabs.

The test results showed that the AC o-g CG performs extremely well and complies with the requirements of the standard – PRD_{AIR} value is 6 times lower and the WTS_{AIR} value is 17.5 times lower than the requirement for asphalt wearing course.

4.4. Skid resistance

Skid resistance is influenced especially by macrotexture and microtexture of pavement surface. When the macrotexture and microtexture increases, the skid resistance also increases.

Macrotexture is a deviation from the ideal flat surface with specific dimensions of 0.5 mm to 50 mm corresponding to the wavelength of the third-octave bands with an average wavelength of 0.5 mm to 50 mm. Macrotexture consists of coarse and fine fractions of aggregates or surface treatment of concrete pavements.

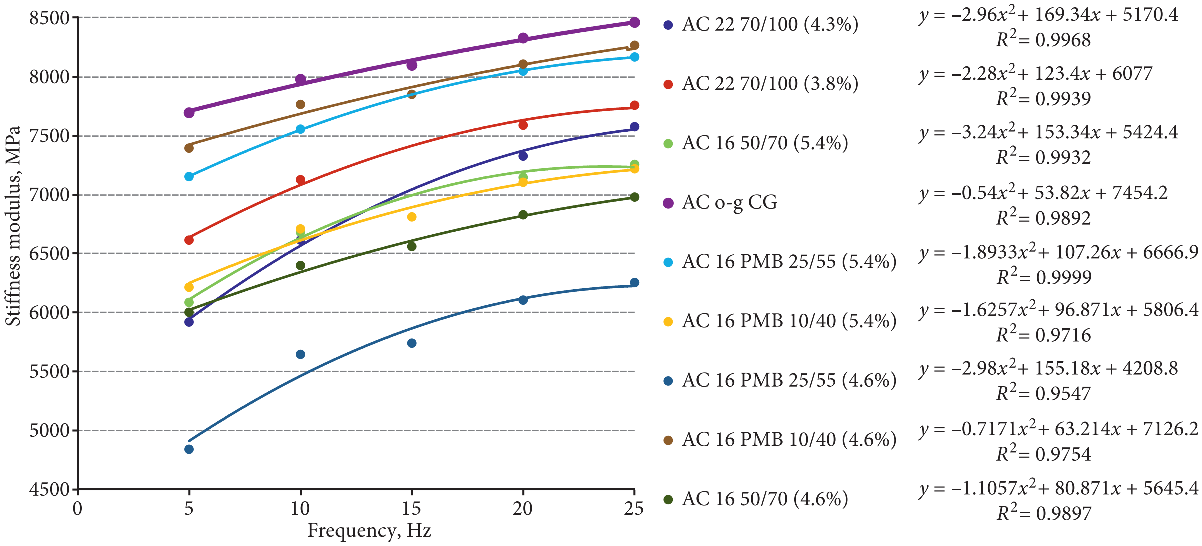

Fig. 3. The relationship between stiffness modulus of AC o-g CG and frequency at temperature +15 °C including a comparison with other common asphalt mixtures

Note: requirements for asphalt concrete according to *EN 13108-1:2006 Bituminous Mixtures – Material Specifications – Part 1: Asphalt Concrete* (5500–9000 MPa)

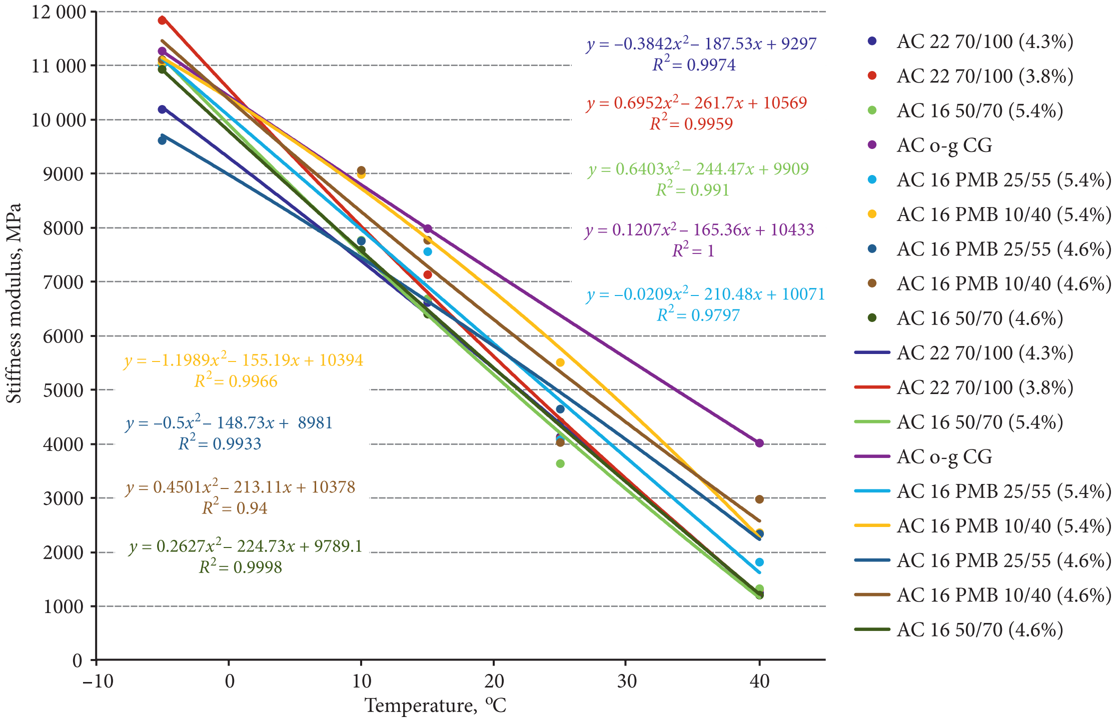

Fig. 4. The relationship between stiffness modulus of AC o-g CG and temperature at frequency 10 Hz including a comparison with other common asphalt mixtures

Table 6. The Thermal Stress Restrained Specimen Test properties of AC o-g CG compared with the commonly used asphalt mixtures with different binders

Mixture	AC 16 50/70 (5.4%)	AC 16 50/70 (4.6%)	AC 16 PmB 10/40 (5.4%)	AC 16 PmB 10/40 (4.6%)	AC 16 PmB 25/55 (5.4%)	AC 16 PmB 25/55 (4.6%)	AC 16 PmB 45/80 (5.4%)	AC o-g CG
Max stress at failure, MPa	3.80	2.87	3.78	2.72	4.08	2.31	4.89	1.45
Temperature at failure, °C	–21.30	–21.00	–17.00	–14.40	–17.60	–16.40	–21.20	–11.20

Note: the value in parentheses represents the binder content.

Table 7. The results of the wheel tracking test of the AC o-g CG and a comparison with the requirements of the Czech National Annex (*NA*) of the standard *ČSN EN 13108-1-NA:2006**

Parameter	Requirement for AC (wearing courses)	Requirement for AC (binder layers)	Requirement for SMA (wearing courses)	AC o-g CG
$PRD_{AIR,\ 10000}$, %	5	3	5	0.8
WTS_{AIR}, mm/10^3 cycles	0.07	0.05	0.07	0.004

Note: * – *ČSN EN 13108-1-NA:2006 Asfaltové směsi – Specifikace pro materiály – Část 1: Asfaltový beton* [Bituminous Mixtures – Material Specifications – Part 1: Asphalt Concrete].

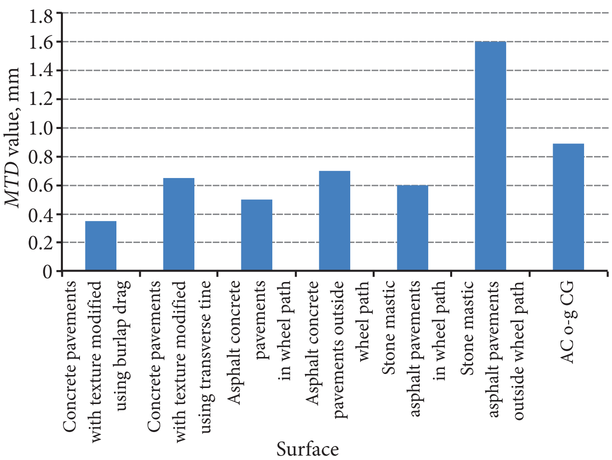

Fig. 5. The comparison of the AC o-g CG and other *MTD* values of the most commonly used surfaces

MTD value = the mean texture depth, expressed in mm, test procedure according to the *EN 13036-1:2010.*

The Czech Technical Guidelines *TP 87 Navrhování* údržby *a oprav netuhých vozovek* [Design of Maintenance and Repair of Flexible Pavements] and the Czech standard *ČSN 73 6177:2009 Měření a Hodnocení Protismykových Vlastností Povrchů Vozovek* [Measuring and Evaluation of the Skid Resistance of Road Pavement Surfaces] were used to evaluate skid resistance by measuring the mean texture depth. The *MTD* value was 0.89 mm, which falls into the first level of classification from five-stage classification (the best classification). This level must be obtained on all roads for the surface of pavements in order to be accepted for the service of the road section.

Other *MTD* values of the different commonly used surfaces, taken from literature, were used for comparison in Fig. 5.

These values clearly show that the designed semi-rigid layers perform quite well in comparison with the other surfaces.

Microtexture is a deviation from the ideal flat surface with characteristic dimensions of less than 0.5 mm corresponding to the wavelengths of the third-octave bands with an average wavelength of 0.5 mm. The microtexture is determined by the size and shape of the individual grains of the aggregate.

Pendulum Test Value (PTV) = loss of energy as the standard rubber coated slider assembly slides across the test surface and provides a standardized value of skid resistance, test procedure according to the standard *EN 13036-4:2011.*

The value of microtexture was determined using the British pendulum test, where the *PTV* value is deducted from a scale. To achieve higher accuracy, the test was repeated five times and the resulting value was given as the average value rounded to the nearest integer. Because the test was performed in a room with a controlled temperature (20±2) °C, no corrections of the value were necessary. Technical Guidelines *TP 87* and the standard *ČSN 73 6177:2009* were used to evaluate skid resistance using the pendulum test. The determined *PTV* value was 63, which falls into the second level of classification from five-stage classification (the second best classification).

5. Conclusions

The open-graded asphalt concrete filled with a special cement grout showed better results than the commonly used asphalt mixtures by stiffness and resistance to permanent deformation characteristics. Also, the specimen of this material showed excellent skid resistance results.

The open-graded asphalt concrete filled with a special cement grout showed better results than common asphalt mixtures by these characteristics:

- Stiffness Modulus at 15 °C and 10 Hz – from 2.8% to 41.2% higher;
- Stiffness Modulus at 40 °C and 10 Hz – from 1.35 times to 3.33 times higher;
- Proportional Rut Depth – from 3.75 times to 6.25 times lower;
- Wheel Tracking Slope – from 12.5 times to 17.5 times lower.

Slightly problematic is the open-graded asphalt concrete filled with a special cement grout behaviour at low temperatures, which could be due to the actual composition of the filling grout (eg the usage of cement of a lower strength or the addition of resins). The Thermal Stress Restrained Specimen Test showed that open-graded asphalt concrete filled with a special cement grout temperature of failure (frost crack) was 36% higher than the average of all the mixtures.

Based on the evaluation of the experimental research result, the authors maintain that the proposed open-graded asphalt concrete filled with a special cement grout complies with all the standard mechanical properties requirements. In addition, other selected properties (mostly functional) were also assessed in order to better understand the behaviour of the layer.

Acknowledgement

The paper was supported by Competence Centres program of Technology Agency of the Czech Republic (TA CR), Project No. TE01020168 Centre for Effective and Sustainable Transport Infrastructure (CESTI).

References

Al-Qadi, I. L.; Gouru, H.; Weyers, R. E. 1994. Asphalt Portland Cement Concrete Composite: Laboratory Evaluation, *Journal of Transport Engineering* 120(1): 94–108. http://dx.doi.org/10.1061/(ASCE)0733-947X(1994)120:1(94)

Anderton, G. L. 2000. *Engineering Properties of Resin Modified Pavement (RMP) for Mechanistic Design*. Geotechnical Laboratory, USA Army Engineer Research and Development Center. Vicksburg, Mississippi. 212 p.

Battey, R.; Whittington, E. 2007. *Construction, Testing and Performance Report on the Resin Modified Pavement Demonstration Project*. Report No. FHWA/MS-DOT-RD-07-137. Mississippi Dept of Transportation, Research and Development Division, Jackson, Mississippi. Federal Highway Administration, Washington D.C. 169 p.

Bhasin, A.; Motamed, A. 2011. Analytical Models to Characterise Crack Growth in Asphaltic Materials and Healing in Asphalt Binders, *International Journal of Pavement Engineering* 12(4): 371–383. http://dx.doi.org/10.1080/10298436.2011.575140

Bražiūnas, J.; Sivilevičius, H.; Virbickas, R. 2013. Dependences of SMA Mixture and Its Bituminous Binder Properties on Bitumen Batching System, Mixing Time and Temperature on Asphalt Mixing Plant, *Journal of Civil Engineering and Management* 19(6): 862–872. http://dx.doi.org/10.3846/13923730.2013.843587

Breakah, T. M.; Bausano, J. P.; Williams R. C.; Vitton, S. 2011. The Impact of Fine Aggregate Characteristics on Asphalt Concrete Pavement Design Life, *International Journal of Pavement Engineering* 12(2): 101–109. http://dx.doi.org/10.1080/10298430903578937

Collop, A. C.; Elliott, R. C. 1999. Assessing the Mechanical Performance of Densiphalt, in *Proc. of the 3rd European Symposium on Performance and Durability of Bituminous Materials and Hydraulic Stabilised Composites*. Ed. by Cabrera, J. G.; Zoorob, S. E.; Cabrera, S. G. 11–12 April 1999, Leeds, United Kingdom. 343–357.

Ding, Q.; Sun Z.; Shen, F.; Huang, S. 2011. The Performance of Semi-Flexible Pavement by the Volume Parameter of Matrix Asphalt Mixture, *Advanced Materials Research* (168–180): 351–356. http://dx.doi.org/10.4028/www.scientific.net/AMR.168-170.351

Gawedzinki, M. J. 2008. *Evaluation of Semi-Flexible (Resin Modified) Pavement.* Report No. I2008-1, Springfield, Illinois, USA. 80 p.

Hajj, E. Y.; Tannoury, G.; Sebaaly, P. E. 2011. Evaluation of Rut Resistant Asphalt Mixtures for Intersection, *Road Materials and Pavement Design* 12(2): 263–292. http://dx.doi.org/10.1080/14680629.2011.9695246

Jacobsen, S. 2012. *The Effectiveness of Grouted Macadam at Intersections – a Life-Cycle Cost Perspective: Degree Project in Highway Engineering.* Division of Road and Railway Engineering, Department of Transport Science (TSC), Royal Institute of Technology (KTH), Stockholm, Sweden. 101 p.

Kanerva, H. K.; Vinson, T. S.; Zeng, H. 1994. *Low Temperature Cracking: Field Validation of the Thermal Stress Restrained Specimen Test*. SHRP-A-401. Strategic Highway Research Program, National Research Council, Washington D.C. 74 p. Available from Internet: http://onlinepubs.trb.org/onlinepubs/shrp/SHRP-A-401.pdf

Laurinavičius, A.; Čygas, D. 2003. Thermal Conditions of Road Pavements and Their Influence on Motor Traffic, *Transport* 18(1): 22–31. http://dx.doi.org/10.1080/16483840.2003.10414059

Lenfant, M. 2012. *High Rutting Resistant Asphalt Pavement*. Seminar 2012: Dept of Highways. Tipco Asphalt Public Company Limited. 269–290.

Liu, C.; Wang, Z. 2003. Effect of Narrow Traffic Lanes on Pavement Damage, *International Journal of Pavement Engineering* 4(3): 177–180. http://dx.doi.org/10.1080/1029843042000198586

Oliveira, J. R. M.; Thom, N. H.; Zoorob, S. E. 2006. Fracture and Fatigue Strength of Grouted Macadams, in *Proc. of the 10th International Conference on Asphalt Pavements.* 12–17 August 2006, Quebec, Canada. 1–10.

Oscarsson, E. 2011. Modelling Flow Rutting in in-Service Asphalt Pavements Using the Mechanistic-Empirical Pavement Design Guide, *Road Materials and Pavement Design* 12(1): 37–56. http://dx.doi.org/10.1080/14680629.2011.9690351

Sivilevičius, H.; Vansauskas, V. 2013. Research and Evaluation of Ruts in the Asphalt Pavement on Lithuanian Highways, *Journal of Civil Engineering and Management* 19(5): 609–621. http://dx.doi.org/10.3846/13923730.2013.817481

Sun, Z. H. 2007. Research on Crack Resistance of Cement Stabilized Macadam Base Course, *Journal of Building Materials* 10(1): 59–65 (in Chinese).

Tarefder, R. A.; Zaman, M.; Hobson, K. 2003. A Laboratory and Statistical Evaluation of Factors Affecting Rutting, *International Journal of Pavement Engineering* 4(1): 59–68. http://dx.doi.org/10.1080/10298430310001593263

Uddin, W. 2003. *Effects of FWD Load-Time History on Dynamic Response Analysis of Asphalt Pavement*, in *Proc. of the 3rd International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control "MAIREPAV03"*. Ed. by Pereira, P.; Branco, F. 7–10 July 2003, University of Minho, Guimarães, Portugal.

Wu, D. Q.; Zhang, Y. 2011. The Semi-Rigid Pavement with Higher Performances for Roads and Parking Aprons, in *Proc. of the CAFEO 29, Sustainable Urbanization – Engineering Challenges and Opportunities.* 27–30 November 2011, Negara, Brunei. 1–7.

Xu, T.; Huang, X. 2012. Investigation into Causes of in-Place Rutting in Asphalt Pavement, *Construction and Building Materials* 28(1): 525–530. http://dx.doi.org/10.1016/j.conbuildmat.2011.09.007

Vaitkus, A.; Laurinavičius, A.; Oginskas, R.; Motiejūnas, A.; Paliukaitė, M.; Barvidienė, O. 2012. The Road of Experimental Pavement Structures: Experience of Five Years Operation, *The Baltic Journal of Road and Bridge Engineering* 7(3): 220–227. http://dx.doi.org/10.3846/bjrbe.2012.30

Vaitkus, A.; Paliukaitė, M. 2013. Evaluation of Time Loading Influence on Asphalt Pavement Rutting, *Procedia Engineering* 57(1): 1205–1212. http://dx.doi.org/10.1016/j.proeng.2013.04.152

Van de Ven, M. F.; Molenaar, A. A. 2004. Mechanical Characterization of Combi-Layer, *Journal of the Association of Asphalt Paving Technologists* 73: 1–22.

Zhuang, S. Q.; Liu, P.; Sun, Z. P. 2003. Investigation on Deformation and Its Influencing Factors of Cement-Stabilized Macadam Base, *Journal of Building Materials* 6(4): 356–363 (in Chinese).

Received 28 November 2014; accepted 12 March 2015