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High Modulus Asphalt Concrete with Limestone Aggregate

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Abstract: Utilization of local and alternative materials (such as steel slag) is one of the main aims of the road building. This concerns both developed and developing countries. One can obviously notice changes and the rise of requirements for road pavements and materials applied. This occurrence observed lasting recent years is mainly the result of the growth of the intensity of road transportation. It is an important task to meet the more stringent requirements without excessively increasing the costs. Problems resulted from the limited accessibility of mineral aggregates appeared with the considerable growth of financial expenditures on road construction as well as logistics and transportation problems in delivery of aggregate from quarries located on the south of Poland to northern and eastern regions. This study is devoted to the applicability of using limestone aggregates, available in central and northern Poland, in the asphalt mixtures. Laboratory tests showed that limestone aggregate may be successfully used in High Modulus Asphalt Concrete for base and binder courses of road pavements. This result is also confirmed by full scale testing using a Heavy Vehicle Simulator.

***Key words**: High modulus asphalt; Limestone aggregate; Pavement; Performance evaluation.*

Need for Application of Local Aggregates

Utilization of locally available materials for highway construction was and still is one of the main aims of the road construction communities. It concerns both developed and developing countries. It is clear that the requirements of high-quality roadway surface and materials have been increasing in recent years because of the rapid growth of highway transportation. However, the use of locally available materials to conserve resources and to limit construction costs is still a major goal.

Problems resulting from the limited accessibility of construction materials, such as mineral aggregates, appeared to become more important during recent years because of considerable growth in financial expenditures on highway infrastructure development and modernization of the Polish road network. Logistics and transportation of good-quality aggregates from quarries located on southern region of Poland to the northern and eastern regions have become problematic and expensive. Utilization of locally available materials becomes economically necessary. If the local material does not meet quality requirements for its intended application, then one should seek ways to improve its proprieties. Another alternative is to find other applications, in which the quality requirement might not be as stringent. Possibility of use of local limestone aggregates in northern and eastern Poland is the good example. The objective of this study was to evaluate the suitability of using limestone aggregates as a component of high modulus asphalt concrete.

High Modulus Asphalt Concrete (HMAC) in Poland

HMAC is an asphalt mixture developed in France. It has been used in France for many years and has gained a lot of interest in other European countries. The HMAC is commonly referred as EME (*Enrobé Modulus Élevé*) in France and as AC WMS in Poland (*acronym in Polish*).

The EME is a special asphalt concrete technology developed in 1980's in LCPC (*Laboratoire Central des Pontes et Chauseé*) in co-operation with road enterprises. EME is an asphalt concrete mixture designed to be used in base and binder courses of asphalt pavement. It has closed structure with comparatively large content of bitumen. Bitumen with harder grades are normally used, mainly 10/20, 15/25, and even 5/15; polymer modified bitumen PmB is also used. Harder bitumen assures the mixture's resistance to permanent deformations and high stiffness mixtures. Large content of bitumen and small content of air voids (closed structure) assure workability, fatigue durability, and water resistance. The EME requirements are one of the first to include performance-based properties, such as workability, stiffness modulus, fatigue life, and water resistance. France was also one of the first countries to introduce mechanistic asphalt pavement design into its general practice. The application of EME in France allowed for thinner asphalt pavement because of higher stiffness modulus, which reduces tensile strains in asphalt base layers.

EME base layers are covered with thin wearing course of BBTM (*Beton Bitumineuse Trés Mince*) mixture, with composition and structure similar to SMA (*Stone Mastic Asphalt*) mixture. The principal difference between BBMT and SMA is that BBTM is a gap-graded mixture with truly non - continuous grading, i.e. lack of fine aggregate (sand) fraction, while limited amount of sand fraction is present in SMA. One advantage of using BBTM is the possibility of laying thinner wearing course than SMA (less than 3.5*cm*, usually 2*cm*). The possibility of incorporation of lower-quality mineral aggregate is one of the primary advantages of EME. The use of stiffer bitumen and the close (dense) structure of asphalt mixture result in the asphalt mixture's high stiffness modulus and resistance to fatigue. Increase in mixture's stiffness reduces tensile strains and stresses in the pavement.

Adoption of EME and BBTM technologies to Polish conditions was initiated in Road & Bridge Research Institute IBDiM in the late

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1990's. The original French technology could not be applied directly because of the different climatic conditions (cold Polish winter), as well as lack of hard grades of road bitumen from Polish refineries at the time (the hardest grade was Pen 45/60). For the first laboratory testing, Multi-grade bitumen Multiphalt Shell was used. First field application took place in 1999 [1]. Further, polymer modified bitumen PMB 10/40-65 was applied in laboratory investigations and industrial applications. At present, plain road bitumen of grade 20/30 is available from Polish refineries. Use of very hard bitumen (10/20 or 15/25 which is used in France) might not be suitable because of the very cold winter conditions in Poland.

The development of the technology and requirements for mix were documented and published by IBDiM in Recommendation Book No. 63 [2], and Book No. 70 [3]. Book 70 includes typical road pavement constructions with HMAC presenting thinner pavements in comparison with pavements of traditional asphalt concrete, as well as longer life pavements designed for 30 years, instead of typical 20 years design service life.

Advantages and Disadvantages of Limestone Aggregate

Limestone and dolomite aggregates have been used for many years in Poland. However, their use has been decreeing in recent years because of more stringent requirements of mechanical and surface properties of road pavements. The decrease of use of limestone aggregates has been observed even in regions where they are locally available and have been used for years. The reason is often excessive caution and fear, in spite of the previous good experiences.

One of the reasons for this fear is the limitation of use of calcareous aggregate in wearing courses in the Catalogue of Typical Flexible and Semi-Rigid Road Pavements [4] - it is recommended to apply mixture of aggregates for wearing course with less than 50% of dolomite aggregate. This recommendation is a result of investigation of SMA wearing courses after their introduction in Poland. The main reason was the need for improvement of friction coefficient of wearing course. This particular recommendation was sometimes read by some designers and road administrations too literally; for instance, it was applied to base and binder courses as well.

The perceived disadvantage of limestone aggregate is its weaker mechanical proprieties. However, many examples of successfully building highway pavements could be referenced from other developed countries. French motorways and roads in the region of Central Massif were built in considerable part from limestone and dolomite aggregates. In the USA limestone and dolomite aggregates are also applied in road pavements. Asphalt mixtures and pavements need to meet objective, performance based requirements, such as stiffness modulus, resistance to rutting, fatigue, resistance to water, and anti-skidding proprieties (the last exclusively for wearing courses). The comprehensive investigations of asphalt mixture designs with various aggregates used in Texas can be a good example [5]. Mixtures containing hard limestone aggregate (applied in asphalt concrete) meet performance based requirements, also for wearing courses.

Numerous papers present results of comparative research of asphalt mixtures with granite and limestone or dolomite aggregates. Conclusions are similar: granite shows better resistance to low temperature cracking than limestone does [6]. However, limestone shows advantage in bitumen-aggregate affinity, and better resistance to water damage [7]. Mixtures with limestone aggregate also exhibited less ageing of bituminous binder [8], also due to better adhesion of bitumen. The penetration of the water to the asphalt pavement may result in the damages of the pavement as a result of the porous pressure exerted by water, especially during the rise of temperature and under vehicles wheel loading. Damages can be caused by the weakness of binder adhesion to aggregate or the cohesion of bitumen between aggregate grains. Acid aggregate (granite) exhibits, in such case, weaker adhesion that can cause washing-up the binder from the aggregate and deterioration by raveling. Basic aggregate (such as limestone) shows weakness of the binder cohesion, which may cause microcracking in the pavement course [9].

One of the advantageous technological solutions is HMAC, which showed controlled resistance to fatigue, rutting, and water damage. At the same time, closed structure of this mixture can protect it from penetration of water.

Laboratory Testing Program

Laboratory tests were performed at IBDiM laboratory. Testing program included (PN-EN stands for European Standards adapted for Polish conditions):

- asphalt mixture design,
- density, PN-EN 12697-5,
- bulk density - hydrostatic method, PN-EN 12697-6,
- air voids content, PN-EN 12697-8,
- stiffness modulus IT-CY (*Indirect Tensile Test – Cylindrical Sample*) at 0, 10, 20°C, PN-EN 12697-26,
- stiffness modulus 4PB (*4 Point Bending Test*) at 10°C, 10*Hz*, PN-EN 12697-26 (AASHTO TP8-94),
- fatigue life 4PB at 10°C, 10*Hz*, PN-EN 12697-24 (AASHTO TP8-94),
- permanent deformation at 60°C, PN-EN 12697-22 (tested in Large Apparatus – LCPC Rutting Tester), and
- resistance to water PN-EN 12697-12.

Properties of Limestone Aggregate from Lafarge Quarry "Kujawy" in Poland

Properties of limestone aggregates are presented in Tables 1 to 3 in comparison to requirements of Polish WT-1 (National Application document) in accordance with European Standard PN-EN 13043.

The results presented in Tables 1 to 3 prove that limestone coarse and fine aggregates, as well as filler meet Polish requirements for use in High Modulus Asphalt Concrete.

High Modulus Asphalt Concrete Composition and Properties

To evaluate applicability of limestone aggregate for HMAC application, the basalt aggregate was used in a reference mixture.

Table 1. Properties of Limestone Coarse Aggregate and Requirements According to WT-1.

Property	Test Result		WT-1 Requirement for HMAC	
	Size 4/8	Size 8/16	KR3÷4	KR5÷6
Grading, Category	$G_C90/10$	$G_C90/10$	$G_C90/20$	
Grading Tolerances, Category	-	-	$G_{20/15}$	
Fines Content, Category	f_1	f_1	f_2	
Shape of Coarse Aggregate, Category	SI_{15} (FI_{10})	SI_{15} (FI_{10})	SI_{40} (FI_{40})	SI_{30} (FI_{30})
Percentage of Crushed and Broken Surfaces in Coarse Aggregate, Category	$C_{100/0}$	$C_{100/0}$	$C_{90/1}$	
Resistance to Fragmentation of Coarse Aggregate, Category	LA_{30}	LA_{30}	LA_{40}	
Particle Density	2.66	2.68	Declared	
Bulk Density	-	-	Declared	
Water Absorption, Category	-	-	$W_{cm}0.5$	
Freeze-thaw Resistance, Category	F_2	F_1	F_4	
Content of Coarse Matter, Category	$m_{LPC}0.1$	$m_{LPC}0.1$	$m_{LPC}0.1$	

Remark: KR3÷4 means the average traffic category, and KR5÷6 the high traffic category

Table 2. Properties of Limestone Fine Aggregate and Requirements According to WT-1.

Property	Test Result	WT-1 Requirements for HMAC	
		KR3÷4	KR5÷6
Grading, Category	G_A90	G_F85 i G_A85	
Grading Tolerances, Category	-	$G_{TC}20$	
Fines Content, Category	f_{10}	f_{16}	
Maximum Methylene Blue Value, Categories	MB_F10	MB_F10	
Angularity of Fine Aggregate, Category	$E_{cs}30$	$E_{cs}30$	
Particle Density	2.56	Declared	
Content of Coarse Matter, Category	$m_{LPC}0.1$	$m_{LPC}0.1$	

Table 3. Properties of Limestone Filler and Requirements According to WT-1.

Property	Test Result	WT-1 Requirements for HMAC
Grading	Fulfilled Requirements for Added Filler	Acc. to Table 24
Maximum Methylene Blue Value, Categories	MB_F10	MB_F10
Water Content	1	1
Particle Density	2.74	Declared
Voids of Dry Compacted Filler (Rigden), Category	$V_{28/38}$	$V_{28/45}$
"Delta Ring and Ball" of Filler Aggregate, Category	$_{R\&B}8/16$	$_{R\&B}8/25$
Water Solubility, Category	WS_{10}	WS_{10}
Calcium Carbonate Content in Limestone Filler, Category	-	CC_{70}
Calcium Hydroxide of Mixed Filler, Category	-	K_a10, K_a Declared
Bitumen Number, Category	$BN_{28/39}$	$BN_{Declared}$

Table 4. Composition of Mineral and Asphalt Mixture of HMAC 16B with Basalt.

Components	Mineral Mixture, % *m/m*	Asphalt Mixture, % *m/m*
11/16 Basalt	19.0	18.0
8/11 Basalt	10.0	9.5
5/8 Basalt	19.0	18.0
2/5 Basalt	12.0	11.4
0/2 Granite	33.0	31.4
Limestone Filler	7.0	6.6
Bitumen 20/30	-	5.1

Basalt aggregate is known for its good mechanical properties and is widely used for heavy traffic roads in Poland. Tables 4 and 5 present composition of mineral and HMAC mixture with basalt and limestone, respectively.

Table 5. Composition of Mineral and Asphalt Mixture of HMAC 16L with Limestone.

Components	Mineral Mixture, % *m/m*	Asphalt Mixture, % *m/m*
4/16 Limestone	40.7	38.4
0/4 Limestone	55.0	52.0
Limestone Filler	4.3	4.1
Bitumen 20/30	-	5.5

Table 6 presents results of laboratory testing of HMAC16B with basalt or HMAC16L with limestone. Comparison of mechanical properties of mixtures for rutting resistance, complex stiffness modulus (from indirect tension test - IT-CY, and from bending test - 4PB), and resistance to fatigue, are presented on Figs. 1, 2, and 3, respectively.

The asphalt mixtures properties were compared to requirements

Table 6. Comparison of Properties of HMAC 16 with Basalt and Limestone.

Property	HMAC16B 4,6%*m/m*	HMAC16B 5,1%*m/m*	HMAC16L 5,5%*m/m*	Requirements Book No. 70
Mineral Mixture Density, g/cm^3	2.850	2.850	2.698	-
Asphalt Mixture Density, g/cm^3	2.636	2.617	2.479	-
Asphalt Mixture Bulk Density, g/cm^3	2.550	2.568	2.403	-
Voids Content in Marshall Specimens, 2 × 75 Blows, % (v/v)	3.3	1.9	3.1	3.0 ÷ 5.0
Permanent Deformation, Large Apparatus, 60 °C, 30 000 Cykli, %	2.7	6.3	3.7	≤ 5
Stiffness Modulus, IT-CY, 10°C, *MPa*	21,118	19,272	23,511	-
Complex Stiffness Modulus, 4PB, *MPa*	19,756	17,950	19,837	≥ 14,000
Fatigue Life, Fatigue Loss D, 10^6 Load Cycles, Strain 130*mm/mm*, %	> 50	49	31.7	≤ 50
Resistance to Water, %	114.9	118,7	95.3	≥ 80

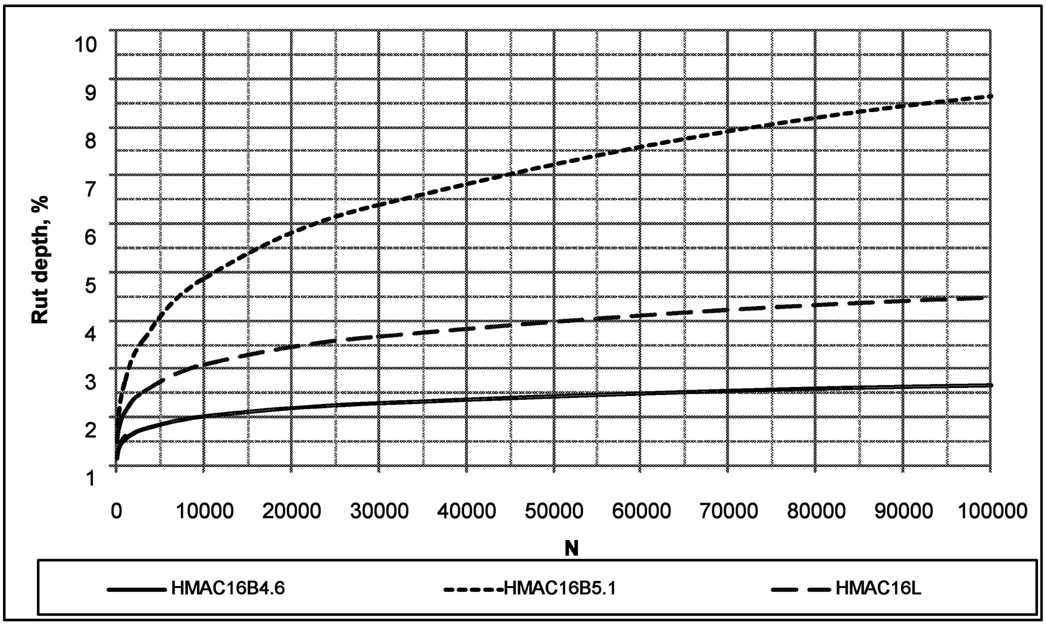

Fig. 1. Rutting Resistance of HMAC Mixture with Basalt (Two Mixtures with 4.6 or 5.1% Bitumen Content) and one with Limestone (with 5.5% Bitumen).

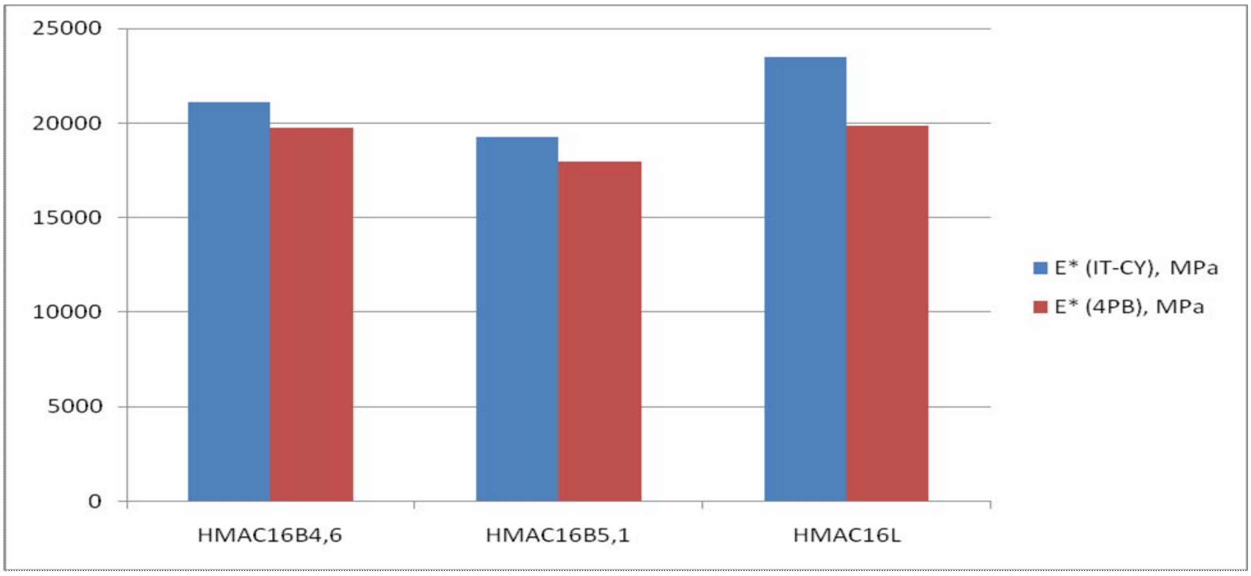

Fig. 2. Complex Modulus of HMAC Mixture with Basalt (Two Mixtures with 4.6 or 5.1% Bitumen Content) and One with Limestone (with 5.5% Bitumen).

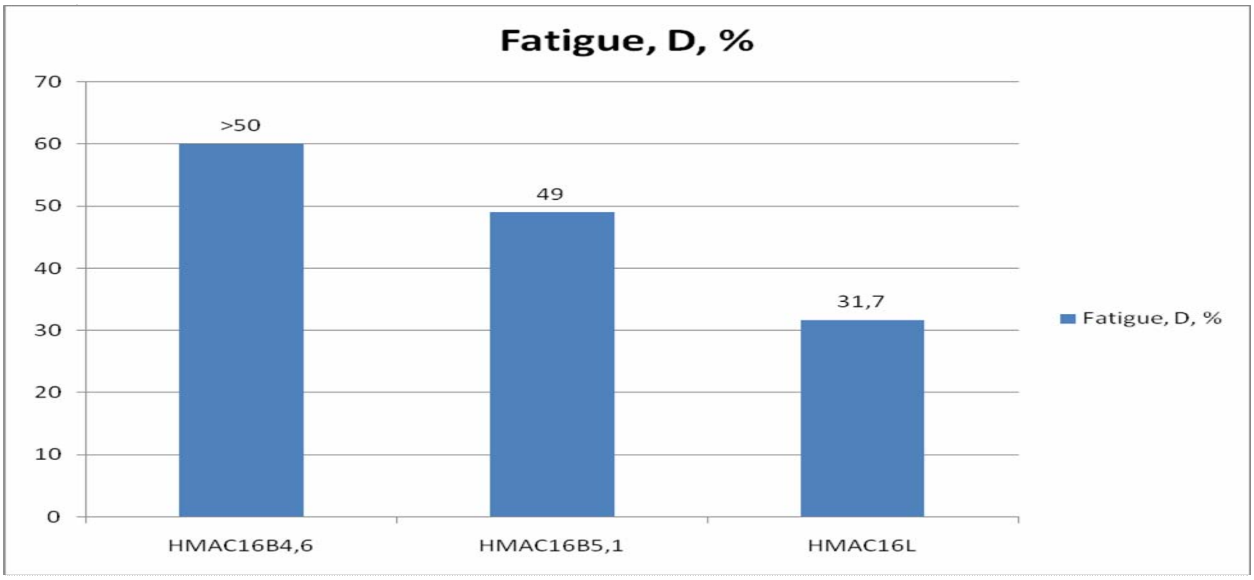

Fig. 3. Fatigue Resistance of HMAC Mixture with Basalt (two Mixtures with 4.6 or 5.1% Bitumen Content) or Limestone (with 5.5% Bitumen); D, % - is the Decrease in Complex Stiffness Modulus Due to Repetitive Loading.

of Book No. 70 It is noted that Basalt asphalt mixture performed unexpectedly. Firstly, mixture designed (with 4.6%*m/m* bitumen) did pass rutting resistance requirement, but did not pass fatigue resistance requirement. Secondly, mixture designed (with 5.1%*m/m* bitumen) did pass fatigue resistance requirement, but did not pass rutting resistance requirement. It is the illustration of basic rules in mix design - lower binder content improves rutting resistance, but the risk arises to meet the fatigue requirement, while higher binder content improves fatigue life, but decreases visco-plastic permanent deformation.

HMAC16L with limestone aggregates passed all requirements. It exhibited higher resistance to rutting, higher stiffness modulus, and longer fatigue life. Higher stiffness modulus and longer fatigue life are of the highest importance for the durability of road pavements. Stiffer asphalt base layer provides better distribution of traffic loading. Tensile strain at the bottom of asphalt base is lower which results in longer life of the pavement. Further, better fatigue resistance provides durability of the pavement under the repetitive traffic loading.

Conclusions

Use of limestone aggregate in High Modulus Asphalt Concrete was evaluated. Comparative testing laboratory was performed on HMAC with basalt (reference) and limestone aggregate.

Test results indicated that limestone aggregates met requirements of Recommendations Book No. 70 for HMAC as well as WT-1 (Polish application document of EN-13043). HMAC16 asphalt mixture containing limestone aggregate fulfilled requirements of Recommendation Book 70. Comparatively, asphalt mixture containing basalt aggregates exhibited problem in its mix design of proper choice of binder content: too low a binder content resulted in poor fatigue life; too high a binder content resulted in poor rutting resistance. Proper laboratory test results of HMAC with limestone aggregate were confirmed in practice in the full-scale test sections using Heavy Vehicle Simulator HVS [10].

Results of tests show that limestone aggregates may be applied without successfully in High Modulus Asphalt Concrete for base and binder courses. Performance based test methods applied in mix design and evaluation prove that the proprieties of mixtures with limestone aggregates meet the standard requirements.

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