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A Review of Aggregate and Asphalt mixture Specific Gravity measurements and their Impacts on Asphalt Mix Design Properties and Mix Acceptance

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Abstract— *Stone Mastic Asphalt (SMA) mixtures rely on stone-to-stone contacts among particles to resist applied forces, and permanent deformation. Aggregates in SMA should resist degradation (fracture and abrasion) under high stresses at the contact points. Current practices for asphalt mix design and acceptance testing rely on volumetric properties. Vital to the calculation of mix volumetric properties are specific gravity measurements of the mixture and the aggregate in the mixture. For the Motorways wearing course,SMA stone grid must fulfil the mineralogical-petrographic condition to be on rock of igneous and/or metamorphic origin but of silicate composition, specific weight and LA method on resistance to fragmentation. During the construction of the Kosovo motorway for wearing course was used the SMA as asphaltlayer for providing longer lifetime to the road construction. The super-pave mix design for SMA wearing course has been composed considering the available stone with high mineralogical and petrographic composition. The stone used for the wearing course on this motorway has resistance to crushing of LA =18 which is below the standard criteria for heavy traffic roads and motorways wearing courses. Thespecific weight of used stone was 3100 kg/m3which is about 15% heavier than standard weight. For this specific stone were prepared special super-pave design mix with binder content 4.5% which was well below than typical SMA composition of 6.0−7.0% binder rather of mixture was 3100 kg/m*^{3}.

In this paperwork it is described the design mix of SMA composed with relatively high specific weight and their impacts on asphalt mix design properties used in Kosovo Motorway.

Key words— SMA design mix,stone grid, structural design ,bitumen content, quality assurance, quality control.

I. INTRODUCTION

Current practices for asphalt mix design and acceptance testing rely on volumetric properties. Vital to the calculation of mix volumetric properties are specific gravity measurements of the mixture and the aggregate in the mixture. In essence, the specific gravity measurements are conversion factors which allow conversion of mass percentages to volume proportions/percentages. The accuracy and reliability of the specific gravity measurements are therefore fundamental to the business of building quality hot-mix asphalt (HMA) pavements.

By the nature of the materials used for construction, it is impossible to design a road pavement which does not deteriorate in some way with time and traffic, hence the aim of structural design is to limit the level of pavement distress, measured primarily in terms of riding quality, rut depth and cracking, to pre-determined values. Generally these values are set so that a suitable remedial treatment at the end of the design period is a strengthening overlay of some kind but this is not necessarily so and roads can in principle be designed to reach a terminal condition at which major rehabilitation or even complete reconstruction is necessary.

Variability in material properties and construction control is always much greater than desired by the design engineer and must be taken into account explicitly in the design process. Only a very small percentage of the area of the surface of a road needs to show distress for the road to be considered unacceptable by road users.

The purpose of structural design is to limit the stresses induces in the sub grade by traffic to a safe level at which sub grade deformation is insignificant whilst at the same time ensuring that the road pavement layers themselves do not deteriorate to any serious extent within specified period of time. Each new structure initially need to be design and calculated, road structure as well,

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There are three main steps to be followed in designing a new road pavement:

1. Estimating the amount of traffic and the cumulative number of equivalent standard axles that will use the road over the selected design life
2. Assessing the strength of the sub-grade soil over which the road to be build
3. Selecting the most economical combination type of pavement, together with the pavement materials and layer thickness that will provide satisfactory service over the design life of the pavement

For Kosovo motorway the Mechanistic-Empirical design method for determination of the layer thicknesses and pavement structure was used. This method takes in consideration, traffic load analysis, climatic and hydrological conditions and materials. Pavement structureis designed for the predicted traffic load for 20 year period of use,starting from year 2014until year 2033.

Traffic load analysis

Because this is totally new motorway connecting corridor X with Adriatic Sea the detail traffic studies were carried out prior to start designing the road structure. The highest AADT (Annual average daily traffic) was around the Capitol Prishtina with the following structure table 1:

Table.1: Distribution of vehicles for traffic calculation

Type of vehicles	Car	Minibus	Pick up	Bus	2-Ax Truck	3-Ax Truck	>3-Ax Truck
percentage	74.7%	3.4%	8.5%	1,1%	6.2%	0.8%	5,3%

Traffic load for pavement calculation is expressed in the total number of equivalent 82 kN axleload passage. The average utilization of vehicle bearing capacity of 85% was applied.The calculation of the equivalent traffic load on both directions during the design period (fromyear 2014 till year 2033) on main route presented,showsthe average number of crossings ESOO relevant for pavement structure dimensioning amountsto: **2.81 x 107 x 0,45 = 1.27 x** $\mathbf{10^{7}}$,which bring this motorway to the heavy traffic load facility.

Climatic and hydrological conditions

Kosovo have continental climate condition with warm summers up to 40 Celsius degree and cold winters up to -25 Celsius degree. Hot and cold periods lasts up to 1 month during the July August respectively cold during January February. The freezing depth is taken 50-70 cm.

Material Quality

The third factor considered in defining the thickness of pavement structure are materials selected for the construction of each individual pavement structure layer. This is particularly important in designing of roads characterized by heavy and very heavy traffic loads and successful selection depends on the knowledge of deterioration mechanisms of each individual material type.The quality of materials for construction of the selected pavement structure layers has to comply with the applicable factors of equivalent resistance to material deterioration underdynamic impact of traffic.

Applicable values of basic materials equivalency selected for this structural designing arepresented in table 2.

Table.2: Material equivalency factor

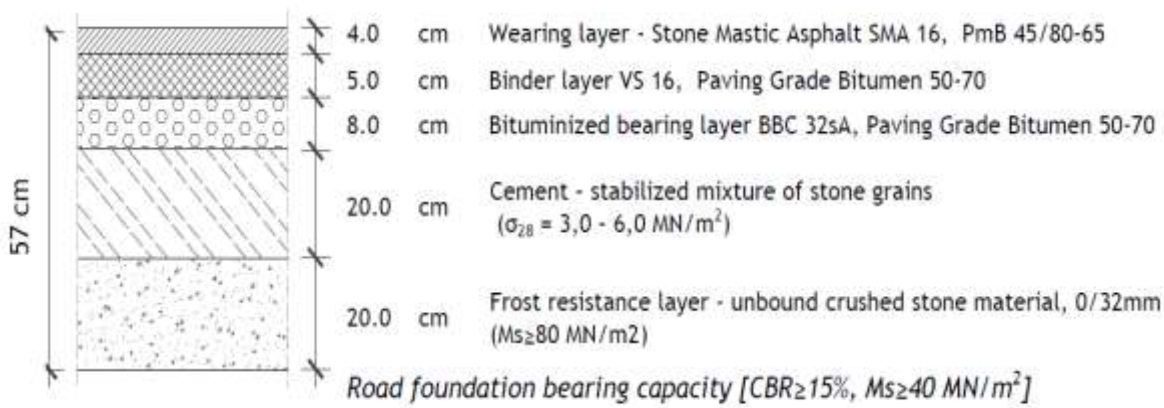
Material type	Equivalency factor a_i
Asphalt concrete AC and Stone Mastic Asphalt SMA – wearing layers	a_1=0.42
Binder layer + bituminized bearing layer	a_2=0.35
Cement Stabilized mixture of stone grains	a_3=0.20
Unbound stone material	a_4=0.14

Selected pavement structure

The adequate thickness of pavement structure was calculated based on the above-mentioned input data and taking in consideration the trafficload. From the calculated traffic load, climatic and hydrological conditions, material in disposal and soil bearing capacity pavement structure type 3 was selected.

Pavement structure 3 is composed by wearing course from Stone Mastic Asphalt (SMA 16)- thickness 40 mm, binderlayer from of VS 16 - thickness 50 mm,bearing layer from bituminizedbearing layer (BBC 32s A) -thickness 80 mm, base layers from cement stabilized layer (CS) - thickness 200 mm and loose crushedstone material (LCSM) -thickness 200 mm.This structure is adequate for the traffic stated above taking considering the average annual traffic grow 4% and for design period 2014 – 2033. The pavement structure is presented at figure 1.

Fig.1: Pavement structure layers



Stone Mastic Asphalt Mixes

Stone Mastic Asphalt is a high stiffness, high macro texture bituminous mixture suitable for use in high demand and/or high speed areas. The high macrotexture compared with asphaltic concrete allows good surface drainage hence reducing the risk of aquaplaning, and also reduces traffic noise compared with chip seals or asphaltic concrete. International evidence has shown that Stone Mastic Asphalt resists the reflection of cracks in underlying layers as well.The process of designing a SMA mixture involves adjusting the grading to accommodate the required binder and void content rather than the more familiar process of adjusting the binder content to suit the aggregate grading.

Commonly used additives are fibres, such as cellulose fibres. Mastic is the mortar comprised of fines, filler, binder and stabilising additive, and may be modified with polymers to improve its rheological properties. The composition of the mastic mortar is a crucial factor contributing to the performance of Stone Mastic Asphalt. Bituminous binder shall be 60/70 penetration grade bitumen. Sufficient stabilising additives shall be added to the Stone Mastic Asphalt to ensure binder drainage does not occur during storage, transportation and construction. The design process for Stone Mastic Asphalt involves adjusting the grading to accommodate the required binder content (minimum of 6% to 7% depending on maximum aggregate particle size) and voids content rather than the traditional design process for other asphalt mixes, of adjusting the binder content to suit an aggregate gradation. Only crushed aggregates are specified for the Stone Mastic Asphalt to ensure suitable aggregate interlock. The use of natural aggregates containing polished or rounded particles, such as sand, is not permitted.

Stone

The use of certain types of stone in the pavement structure asphalt courses depends on the mineralogical and petrographic composition, the physical and mechanical properties and the granular stone materials production technology.

Quality requirements

Stone quality as raw material for production of granular stone material must fullfill the conditions in order to be used for the asphalt pavements, some of the criterias are shown at the Table 3.

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Table.3: Criteria for stone grid

Property	Quality of physical and mechanical properties of crushed stone grid		
	K- I	K- II	K- III
Mineralogical –petrographic division	Igneous group	Igneous and carbonate group	Carbonate group
Compressive strength in dry state, minimum Mpa	160	140	120
Resistance to wear by sanding, maximum $cm^3/50\ cm^2$	12	18	22
Water absortion,maximum, % (m/m)	0.75	0.75	1.0
Resistance to frost	Resistant	Resistant	Resistant
Resistance to crushing (Los Angeles) maximum % (m/m)	**16**	18	22

II. ASPHALT MIX DESIGN PROPERTIES

Due to the fact that close to the Motorway site it was not available stone quarry with stone resistance to crushing LA < 16 as it is requested by the EN standard for stones, it was taken in consideration to design a new asphalt mix using the stone granular from the quarry close to the Motorway (MIM Golesh quarry) with following to major characteristics: Stone resistance factor to crushing**LA =18**Density of stone material mix **ρ_{smm}=3100 kg/m^3**

The new super pave asphalt design mix was prepared for wearing course from stone mastic asphalt with this stonewith maximum (nominal) particle size of 16 mm (SMA 16 mm). For new asphalt design mix were prepared 6 samples for initial job mix formula according to standard procedures.

Table.4: Composition of designed mixtures of stone material fractions.

	AM1	AM2	AM3	AM4	AM5	AM6
Relation P(KB)/P(FKM)	2,4	2,4	2,4	2,9	3,7	5
Percentage of filler in KM[%m/m)]	6,5	6,5	6,5	7,0	8,4	10,0
Extracted filler from SKM [%m/m)]	0,3	0,3	0,3	5,9	4,7	9,3
Coefficient for RF	5,05	5,05	5,05	5,73	7,27	9,17
Coefficient for 0/4	21,90	21,90	21,90	21,68	21,34	20,85
Coefficient for 4/8	16,11	16,11	16,11	16,01	15,74	15,43
Coefficient for 8/11	15,53	15,53	15,53	15,43	15,17	14,87
Coefficient for 11/16	41,41	41,41	41,41	41,16	40,47	39,68

Table.5: Composition and properties of designed asphalt mixtures.

	AM1	AM2	AM3	AM4	AM5	AM6
Density of mixture FKM [t/m^3]	3,070	3,070	3,070	3,067	3,061	3,054
Density AM [t/m^3]	2,829	2,863	2,881	2,816	2,818	2,820
Percentage of bitumen content in AM [%(m/m)]	4,12	3,49	3,18	4,33	4,20	4,04

Bitumen density: The density of bitumen used for preparation of asphalt mixtures and test specimen made according to Marshall Method (EN 15326), PicknometerMethod ρB=100,1 kg/m^3). Bitumen type is PmB 45/80 – 65 (Ex –Fis), and the bitumen content in asphalt mix design is 4.5 %.

Additives: used at the design mix were: Fibres ,, Arbocel ZZ 8/1 with share in design mix 0.4 % and ,,Interflow – T'' as chemical additive with share id design mix 0.6%.

The final mix design for wearing course of highway with stone mastic asphalt of stone material with maximum (nominal) particle size of 16 mm (SMA 16 mm) was accepted with following distribution See table 6.

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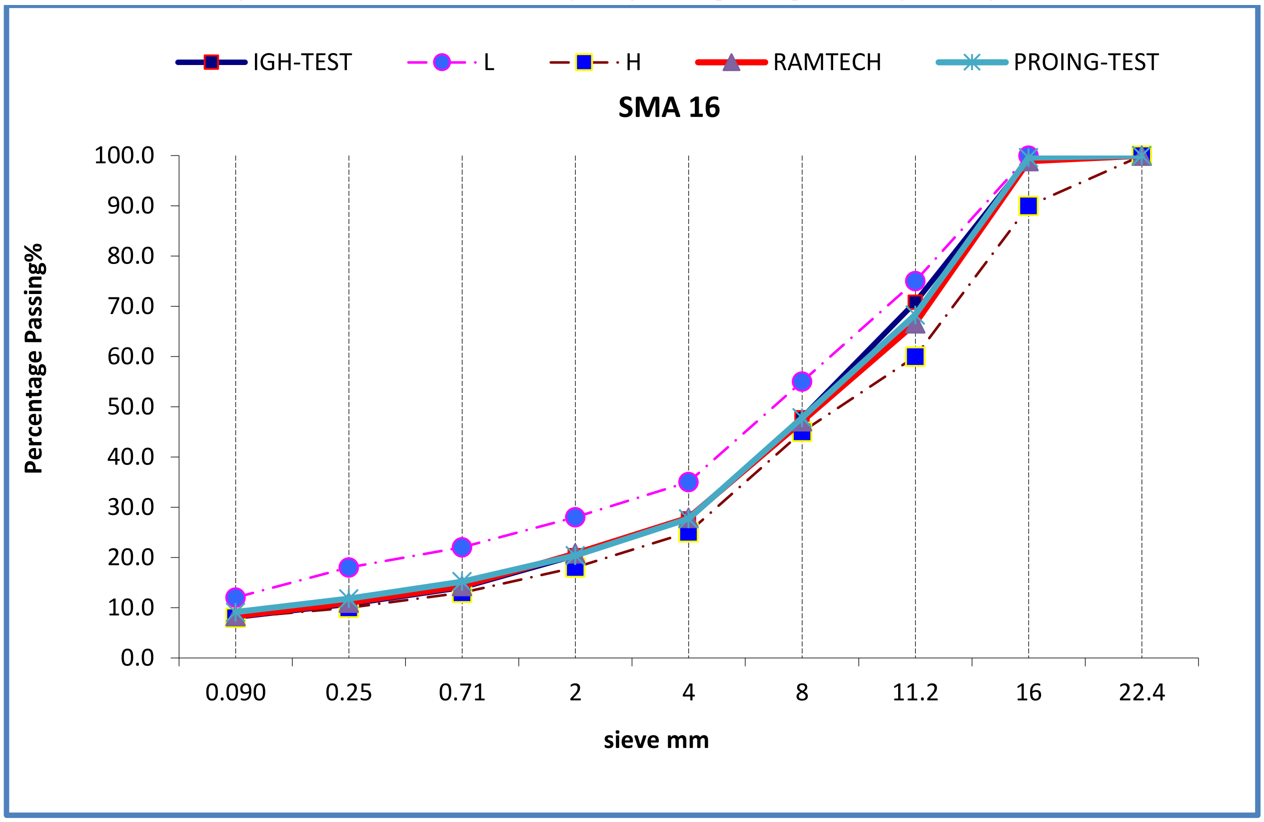
Table.6: New asphalt mix design for wearing course type: split mastic asphalt

ASPHALT MIX DESIGN			
Stone material	Aggregate fraction	Share in mix [%(m/m)]	Density [kg/m^3]
Cement	Filler	6.7	3000
MimGolesh	0-4	21.6	3108
MimGolesh	4-8	16.7	3107
MimGolesh	8-11	18.5	3096
MimGolesh	11-16	36.5	3120
Density of stone material [t/m^3]			**3105**
Type of bitumen			PmB 45/80-65
Density of bitumen [t/m^3]			1,012
Bitumen content in AM design			**4.5%**
Additive ; Fibres ,, Arbocel ZZ 8/1			0.4%
,,Interflow – T''			0.6%

Fig.2: Grain size distribution diagram for accepted asphalt design mix of SMA



III. TESTING OF ASPHALT MIX DESIGN AND RESULTS OBTAINED

A trial section was prepared in order to test the new asphalt mix design in order to check workability of new mix design with length of 300 m. The following tests were performed during the trial test:

- ✓ Asphalt mixture temperature during loading into the finisher from every delivery,
- ✓ Composition and the physical and mechanical properties of asphalt mixture on at least three samples
- ✓ Change in the rate of compaction of the asphalt layer by non-destructive method during placing and on cooled asphalt layer at six points minimum,

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- ✓ Rate of compaction, percentage of voids, thickness of executed layer and the adhesive binder strength with the base, on at least three original samples,
- ✓ Evenness of each traffic lane in the full trial section length,
- ✓ Skid resistance (for wearing layers) on at least three points, and Results are presented at the table 7

Table.7: Physical-mechanical properties an laboratory testing results for asphalt mixture Stone Mastic asphalt SMA

No.	Technical characteristics		Test standard	Laboratory Results	Quality conditions	Category EN 13108
1(a)	Void content, Vmax	[%]	EN 12697-8	4.5	3 - 6	Vmax6 Vmin3
2(a)	Voids filled with bitumen, VFB max	[%]		73.8	71 - 83	VFBmax83
3(a)	Voids filled with bitumen, VFB min	[%]				VFBmin71
4(b)	Drained material, D	[%]	EN 12697-18	0.11	≤0,6	D0,6
5(c)	Indirect tensile strength ratio, ITSR [%]		EN 12697-12 EN 12697-23	86.93	≥ 80	ITSR80
6(d)	Wheel tracking slope, WTSAIR	[%]	EN 12697-22	0.038	≤ 0.07	WTSAIR 0.07
7(d)	Proportional rut depth, PRDAIR	[%]		4.63	≤ 5.0 [%]	PRDAIR5.0
8(e)	Stiffness	[MPa]	EN 12697-26	4022	3600 - 7000	Smin3600
9	Bulk Density	[kg/m^3]	EN 12697-6	2702	-	-
10	Maximum Bulk Density	[kg/m^3]	EN 12697-5	2828	-	-
11	Degree of compaction, min.	[%]	EN	98	98	Min 98
12	Stability	[kN]	EN 12697-34	8.8	-	-
13	Deformation	[mm]		3.9	-	-
14	S/D	[kN/mm]		2.3	-	-
15	Bitumen cont. in AM	[%]	EN 15326	4.5	6-7%	-

Results from trial section proofed that the super pave asphalt design mix for the wearing course from stone mastic asphalt full fill conditions for using stone from MiMGolesh quarry for producing the SMA.

So far 60 km of dual motorway carriageway are paved with this stone and the results followed up by QC satisfy conditions set up by EN standards for this material.

IV. CONCLUSION

- Stone quality as raw material for production of granular stone material must fullfill the conditions standards or general technical requirements –GTR in order to be used for the asphalt pavements.
- Sometimes can be considerd stone for producing the granular material with the higher resistance on fragmentation and higher specific weight than standard or GTR specify.
- Superpave design mix with stone granular material with higher spefic weight than optimum stones requires less bitumen in the design mix.
- Designer who prepare the super pave design mix need to consider parallel testing of the new design mix with the design mix which was used on previous project as reference and proofed that it was adequate design mix.
- In our case by parallel testing of reference aggregate it was found that this aggregate has similar resistance to degradation which is measured by compaction of

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marshal sample, despite the fact LA coefficient was found to be La=13%.

- SMA design mix used in Kosovo motorway requires less energy for the compaction than reference design mix,
- Higher specific weight of stone increase the total volumetric weight.
- With increase of weight with specific percentage the contractor must decrease the unit price for that percentage because the asphalt wearing course mass is same for two different stone materials even the specific weights change.

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