Article

Environmental Performance of Road Asphalts Modified with End-of-Life Hard Plastics and Graphene: Strategies for Improving Sustainability

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Supplementary materials

S1. Road characteristics

The W18 performance parameter indicates on a logarithmic scale the number of acceptable equivalent single axels loads (EALs) at 18lb, that the pavement withstand before reaching the fixed degree of final deterioration caused by the passage of real vehicle axles, calculated according to AASHTO 1993 Design Factors.

$$log_{10}(W_{18}) = Z_R \times S_O + 9.36 \times log_{10}((0.3937 \times SN) + 1) - 0{,}20 + \frac{log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{0.40 + \frac{1094}{((0.3937 \times SN) + 1)^{5.19}}} + 2.32 \times log_{10}(M_R) - 3.056 \quad (1)$$

The expression and the values were provided by companies and are referred to high traffic main and secondary road (4000000 heavy vehicles). The parameters are:

Parameter	Unit	Description	Value
W_{18}	ESALs (Single Axle Loads)	Expected number of 80 kN loads that the pavement will have to withstand over its design life	To be calculated
Z_R	-	Reliability factors of the pavement, expressed by the probability that the number of load applications N that a pavement can withstand before reaching a predetermined degree of deterioration is greater than or equal to the number of load applications N that are actually applied to the structure.	-1,282
S_0	-		0,45
SN		Structural Number, which is an index depending on the structural coefficient of the layer under consideration and its thickness: $a_1D_1m_1 + a_2D_2m_2 + a_3D_3m_3$ where a_i is the coefficient of layer *i* (a function of the nature of the component materials and how they are processed), D is its thickness and m is the drainage coefficient.	To be calculated
ΔPSI		Difference in service index between initial situation P_i and final situation P_f	P_i: 4,1 P_f: 2,5
M_R	PSI	Resilient module of the substrate	90 MPa

Supplemental Table S1-Synoptics of the different compared cases with standard thickness.

Type of asphalt mixtures (AM)	Layer	SN_l	a_i	SN_t	W18 (ESALs)	Thickness (cm)
Standard AM (SAM)	Wearing	2.22	0.44		1 897	5
	Binder	3.18	0.53		10 037	6
	Base	5.25	0.38	10.65	169 201	14
SBS modified AM (SBS-MAM)	Wearing	2.60	0.52		3 793	5
	Binder	3.48	0.58		16 053	6
	Base	5.69	0.41	11.77	287 533	14
Asphalt mixture modified with the innovative modifier (innovative-MAM)	Wearing	2.95	0.59		6 990	5
	Binder	3.96	0.66		34 586	6
	Base	6.70	0.48	13.61	738 502	14

In case of reduction thickness (second case) the value of SN is kept the same for each slabs consider, so is possible to calculate the thickness without remove the structural characteristic of road pavements.
Considering a weak dependence of the drainage coefficient on thickness within this thickness changes range, one may approximate the drainage coefficient constant (m=1).
If the structural number is also set to constant in the i[th] slab, if the corresponding i[th] slab stiffness coefficient in the case under comparison is higher, the following relation holds:

$$a_i'\cdot D'_i = a_i\cdot D_i \quad (4)$$

where the prime refers to quantities of the MBCs. Given the value of the measured MBC stiffness coefficient ai', allows changing (reducing) the slab thickness D'_I accordingly, so that to keep the product $a_i\cdot D_i$ of the known BC slab unchanged. This will assure the condition:

$$SN_i' = SN_i \quad (5)$$

The service parameters in the second scenario are defined by the traffic intensity of 4.000.000 vehicles per year and by considering a service time over a period of 20 years. Within the service time-frame of 20 years, the road pavement slabs standard maintenance is included. In this case, the frequency of road maintenance is kept the same for all three compared cases.

Supplemental Table S2- Synoptics of the different compared cases with reduced thickness.

Type of asphalt mixtures (AM)	Layer				W18 (ESALs)	Thickness

		SN_l	a_i	SN_t		(cm)
Standard AM (SAM)	Wearing	2.22	0.44		1897	5
	Binder	3.18	0.53		10037	6
	Base	5.25	0.38	10.65	169201	14
SBS modified AM (SBS-MAM)	Wearing	2.22	0.52		1897	4.3
	Binder	3.18	0.58		10037	5.5
	Base	5.25	0.41	10.65	169201	12.9
Asphalt mixture modified with the innovative modifier (innovative-MAM)	Wearing	2.22	0.59		1897	3.8
	Binder	3.18	0.66		10037	4.8
	Base	5.25	0.48	10.65	169201	11

S2. Road maintenance

The service life of each slab is technically pre-determined by the fatigue resistance performance of the AM mixtures. The fatigue curves obtained for the different slabs provided a confirmation of the expected durability extension factor provided by the innovative solution (super-modifier).

Supplemental Table S3- Frequency of maintenance for each slab for the first case (standard thickness)

Type of bituminous conglomerate	**Layer**	**Service life (years)**	**Useful Life (years)**	**Maintenance frequency**
SAM	Wearing	20	5	20/5
	Binder		10	20/10
	Base		20	20/20
SBA-MAM	Wearing	20	8	20/8
	Binder		16	20/16
	Base		32	20/32
innovative-MAM	Wearing	20	15	20/15
	Binder		30	20/30
	Base		90	20/90

Supplemental Table S4- Frequency of maintenance for each slab for the second case (reduced thickness)

Type of bituminous conglomerate	**Layer**	**Service life (years)**	**Useful Life (years)**	**Maintenance frequency**
SBC	Wearing	20	5	20/5
	Binder		10	20/10
	Base		20	20/20
MBC with SBS	Wearing	20	5	20/5

	Binder		10	20/10
	Base		20	20/20
MBC with super-modifier	Wearing	20	5	20/5
	Binder		10	20/10
	Base		20	20/20

S3. Composition of the innovative modifier

Supplemental Table S5- Ingredients for producing the innovative modifier

Material	Unit	Amount	Transport-Distance	Unit
Waste plastic	t/a	1061,6	23,4	km
PVB	t/a	182,1	60	km
Graphene	t/a	0,97	71	km
Adhesion promoter	t/a	48,4	6,2	km
Packaging (cardboard and polypropylene)	kg	70	128	km
Electricity	kWh	441553,7	-	-
Water	Kg	712800	-	-

Supplemental Table S6- Ingredients for producing the graphene

Graphene composition				
Graphite	t	1	20000 (by ship and by truck)	km
Sulfuric Acid 95%	t	2,26	1000	km
Nitric Acid 62%	t	1,32		
Argon	t	1,120	19	km
Packaging (cardboard and polypropylene)	kg	7,6	-	-
Electricity	kWh/kg	48	-	-