

Mechanical performance under dynamic loading of rubberized asphalt mixtures with highly-porous vesicular aggregate

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Supplementary Information

1. Tables

Table S1. Characterization properties of the volcanic aggregate

	Aggregate fractions				Specified values by technical regulations
	# 10–20 mm	# 4–10 mm	# 0–4 mm	Mineral filler (# < 0.063 mm)	
Lithotype	Vesicular and scoriaceous grey basalt (B-V)			100% CEM II/B-P 32.5 R [EN 197-1]	-
% (by wt. of total aggregate)	20.93	36.27	38.88	3.92	-
ρ_a^a (Mg/m ³)	2.89	2.88	2.45	-	-
ρ_{ssd}^b (Mg/m ³)	2.63	2.56	2.36	-	-
ρ_{rd}^c (Mg/m ³)	2.35	2.37	2.23	-	-
WA ₂₄ ^d (%)	5.8	8.3	15.5	-	≤ 3 – 3.5 % (*); ≤ 6 – 7 % (**)
FI ^e	6	6	-	-	≤ 20 – 30
Cc ^f	56	60	-	-	≥ 70 – 100
SE ₄ ^g	-	-	73	-	> 55
LA ^h	29	28	-	-	≤ 20 – 25
M _{DE} ⁱ	17	23	-	-	≤ 16 – 18
PSV ^j	60	60	-	-	≥ 50 – 56

^aParticle density [apparent] [EN 1097-6]; ^bParticle density [saturated surface dry] [EN 1097-6]; ^cParticle density [dry] [EN 1097-6]; ^dWater absorption of particles after 24 hours [EN 1097-6]; ^eFlakiness index [EN 933-3]; ^fPercentage of particles with more than 50% of their surface crushed or broken [EN 933-5]; ^gSand equivalent of fraction 0-4 mm [EN 933-8]; ^hLos-Angeles coefficient [EN 1097-2]; ⁱMicro-Deval coefficient [EN 1097-1]; ^jPolished stone value [EN 1097-8]; (*)Recommended limits for structural cement concrete; (**)Recommended limits for recycled aggregates.

Table S2. Particle size distribution of reclaimed CRM from used tyres

Particle size [EN 933-2] (mm)	% passing
1	100.0
0.5	94.1
0.25	23.7
0.125	3.7
0.063	0.4

Table S3. Characterization properties of the asphalt binders

		Ref. mixtures ^a	RA mixtures ^b
Bitumen type	Penetration Grade	35/50	CRMB 35/50 ^g
	Performance Grade	PG 70-16	PG 76-10
% (by wt. of mixture)		5.0 – 7.0	5.5 – 7.0
Density ^c (Mg/m ³)		1.042	1.028
Pen. ^d (x10 ⁻¹ mm)		44	38
Soft. Point R&B ^e (°C)		51.6	64.2
Viscosity ^f (cP)	at 60 °C	51,000	215,000
	at 135 °C	600	2,100
	at 150 °C	250	890

^aReference mixtures without rubber; ^bRubberized asphalt mixtures; ^cBitumen density according to EN 15326; ^dPenetration at 25 °C, 100 g, 5s [EN 1426]; ^eSoftening point by Ring-and-Ball test [EN 1427]; ^fDynamic viscosity by Brookfield rotational viscometer [EN 13302]; ^gComposition of CRMB 35/50 (by wt.): 10% crumb rubber modifier, 90% bitumen 50/70 pen.

Table S4. Laboratory tests and equations used to calculate the different mechanical properties of the mixtures, according to standards

Properties	Laboratory test [test standard]	Equation	Test measurements and results [unit]
Thickness variation vs. compaction energy	Compactability [EN 12697-10]	$\frac{1}{t(E)} = \frac{1}{t_{\infty}} - \left(\frac{1}{t_{\infty}} - \frac{1}{t_0} \right) \cdot \exp\left(\frac{-E}{T}\right)$	(Eq. 1) (t(E)) thickness of the compacted specimen as a function of the compaction energy [mm]; (t _∞) minimum possible thickness of the specimen [mm]; (t ₀) initial thickness of the specimen [mm]; (E) compaction energy by impact, expressed considering 21 Nm/blow; (T) resistance to compaction by impact [number of blows]
Stiffness	Dynamic stiffness modulus [EN 12697-26]	$S_m = \frac{F \cdot (\mu + 0.27)}{(z \cdot h)}$	(Eq. 2) (S _m) Stiffness modulus measured by the test [MPa]; (F) maximum vertical load applied [N]; (z) horizontal strain amplitude during the loading cycle [mm]; (h) average specimen thickness [mm]; (μ) Poisson ratio [a constant value of 0.35 was assumed].
		$S'_m = S_m \cdot \{1 - 0.322 \cdot [\text{Log}(S_m) - 1.82] \cdot [0.6 - k]\}$	(Eq. 3) (S' _m) Stiffness modulus corrected for a load surface factor of 0.6 [MPa]; (k) load surface factor measured
Fatigue law under cyclic loading	Resistance to fatigue [EN 12697-24]	$\text{Log}(\varepsilon_0) = a_0 + a_1 \cdot \text{Log}(N)$	(Eq. 4) (ε ₀) initial strain amplitude; (N) load cycles until fatigue failure; (a ₀ , a ₁) material constants obtained from the 4PB-PR fatigue test
Ultrasonic elastic constants	Ultrasonic pulse velocity [EN 12504-4] [BS 1881: Part 203] [ASTM D2845-00]	$G = D_b \cdot V_s^2$	(Eq. 5) (D _b) bulk density of the material [kg/m ³]; (V _s) shear-wave velocity [m/s];
		$E = G \cdot \frac{(3 \cdot V_p^2 - 4 \cdot V_s^2)}{V_p^2 - V_s^2}$	(Eq. 6) (V _p) compression-wave velocity [m/s]; (G) shear modulus [Pa]; (E) Young's modulus [Pa];
		$\mu = \frac{(V_p^2 - 2 \cdot V_s^2)}{2 \cdot (V_p^2 - V_s^2)}$	(Eq. 7) (μ) Poisson's ratio

2. Figures

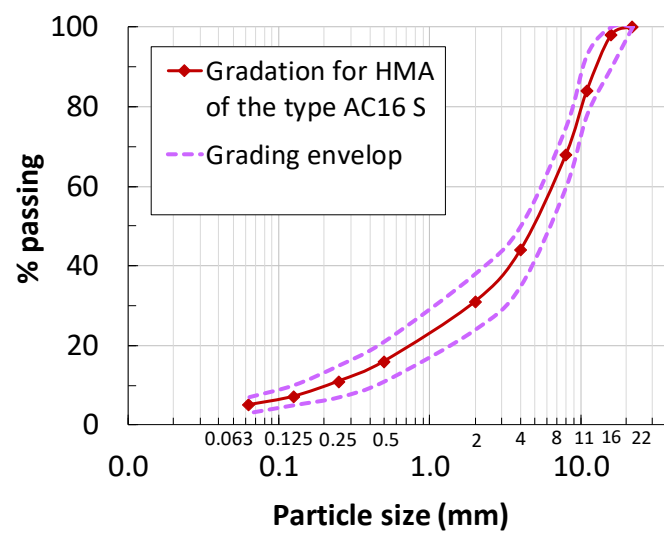
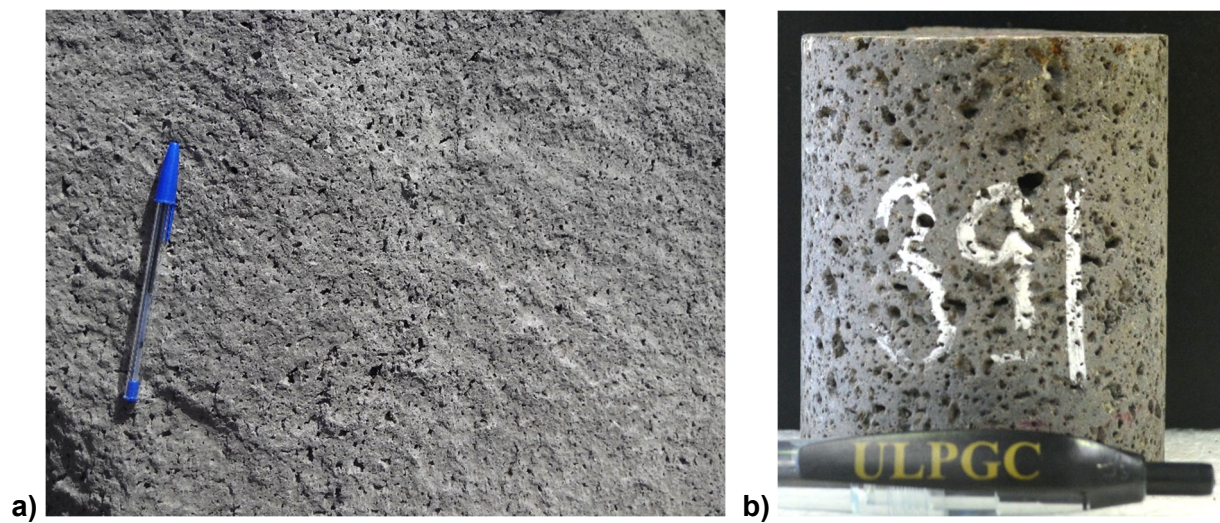


Fig. S2. Grading curve and limits of the grading envelope specified for semi-dense asphalt concrete (AC16 S)