Use of expanded clay for the mix design of high-grip bituminous wearing courses

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SYNOPSIS

The required increasing needs for both safety and comfort for the road users, obliges the Road infrastructures Researchers to look for innovative material which could be successfully used for bituminous wearing courses.
More precisely, the use of non-conventional aggregates, as for the case of expanded clay (EC), involves a significant improvement in the performances of a bituminous concrete from the standpoint of grip as well as of both micro and macro texture and noise reduction, the mechanical characteristics being comparable or, in case, even better than an ordinary conglomerate made of natural aggregates.
Generally speaking, there are some previous studies in literature on the aggregates substitution, from the standpoint of weight, with different percentages of expanded clay .
In order to save the particle size of the blend coming from the mix design procedure, the writers suggest the change of aggregates with expanded clay from the point of view of volume, so as to consider the large difference of the values of the apparent absolute gravity between expanded clay itself and natural aggregates.
As a matter of fact, this study proposes the results of an experimental investigation on the performances of both a traditional bituminous concrete with silica aggregates and a SMA (Splittmastix Asphalt) made of calcareous and basaltic aggregates, 10 and 30% of the volume percentages of aggregates having been changed with structural expanded clay.
The results are significant from the viewpoint of the failure domains tested by means of the UNIBAS M.P.T (UNIBAS Triaxial Test Apparatus) procedure and of the increase of superficial grip or micro and macro-texture.
Furthermore, the study highlights the positive environmental aspects deriving from both the use of artificial aggregates and the reduced need of bitumen when expanded clay is used.

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INTRODUCTION

During the mix design process of a bituminous concrete fundamental is the evaluation of the kind of aggregates which are to be used, from the grading curve standpoint, the mineralogy and the chemical, physical and mechanical properties being considered also.
Recently, several studies were carried out, in the road construction sector, on the use of artificial materials as substitutes for natural aggregates, with a special interest for those materials industrially produced.
At present, there is a strong stimulation for the use of such artificial materials with special regards to the good mechanical properties and the high micro-texture achieved: in any case, every consideration on the matter depends upon economical considerations, the production and use costs being fundamental.
Amongst the alternative materials, the expanded clay (EC) found the interest of the Authors, especially if used for both traditional bituminous concrete and SMA (Splittmastix Asphalt).

EXPANDED CLAY

Expanded clay is an artificial aggregate obtained from the firing of special clays with particular chemical characteristics, in rotating kilns.
The product shows up as a granular material with an alveolar nucleus and a highly rough external surface, characterised by a significant lightness and a good mechanical resistance.
In addition, expanded clay is a non-flammable material, organic substances-free and with a basic pH which allows a good mixing with bitumen inside bituminous concretes.
Furthermore, expanded clay proves itself as having good resistance against wear and tear and abrasion. Indeed, the surface performances, as well as the transversal friction coefficient (CAT) value, were found to be reliable with time [9].
Now expanded clay is used in road constructions to prepare bituminous admixtures for:

- wearing courses with high superficial grip;
- lightweight bituminous concretes;
- recycling.

There are different strength and density classes of expanded clay and, for the road construction purposes, the most commonly used kinds are:

1. “normal” expanded clay, with the following features:
   - particle size: 3÷8mm;
   - admixture density: 320÷370kg/m^3;
   - crushing resistance: (UNI 7549/7) > 12daN/cm^2;
   - Polish Stone Value (C.L.A. - CNR B.U. n.140/92) > 0,64;
2. “tough” expanded clay, with the following features:
   - particle size: 3÷11mm;
   - admixture density: 420 ÷470kg/m^3;
   - crushing resistance: (UNI 7549/7) > 25daN/cm^2;
   - Polish Stone Value (C.L.A. - CNR B.U. n.140/92) > 0,66;
3. “structural” expanded clay, with the following features:
   - particle size : 5÷15mm;
   - admixture density: 550÷650kg/m^3;
   - crushing resistance: (UNI 7549/7) > 35daN/cm^2;
   - Polish Stone Value (C.L.A. - CNR B.U. n.140/92) > 0,66.

One should consider that, with a special production cycle and special clays, some particular clay can be obtained from the rotating kilns, with an expansion degree lower than the traditional material and with a less expanded inner porous nucleus, the outer structure being thicker and more resistant.
These different inner features allow the structural expanded clay to get to a higher absolute gravity and to an increased value of the compressive strength of the grains; as a matter of fact, the use of this material is

particularly indicated for such application where lightweight materials with a good mechanical resistance are required.

THE USE OF EXPANDED CLAY

Generally speaking, the use of expanded clay into bituminous admixtures is based on a weight change of the natural aggregates.
The Authors have some criticism on this way of operating: indeed, according to them, as expanded clay is a material significantly lighter than the others which are commonly used for the manufacture of a bituminous concrete, the weight change does not save the original grading curve, as the use of a higher volume of aggregates involves a higher porosity of the substance manufactured, the overall characteristics of the material itself being different from a volumetric point of view.
Since the volumetric properties are fundamental for the bituminous concretes and for SMA performances, the Authors concentrated their efforts in investigating the volume change of aggregates, rather than the weight substitution.

UNIBAS M.P.T. TEST

The Author, in order to characterize the mechanical performance of the bituminous concretes defined in the study, employed the innovative UNIBAS M.P.T. testing procedure which have not been coded by international technical normative yet.
The apparatus UNIBAS M.P.T. [2], [7], [8] [10] can put a cubic specimen under different stresses long three axles mutually orthogonal. The principal components are three orthogonal actuators, one central electro-hydraulic commanded by a programmable controller and a Personal Computer for the general control and the data acquisition.
The MPT apparatus can vary, at a fixed temperature, in an independent way, the following parameters:
- I_1 first invariant of the tensions tensor;
- J_2 second invariant of the tensor of the deviatoric stresses;
- μ Lode parameter;

In particular, through the application on the specimen of tensional status really triaxial, chosen the value of μ for each test, it is possible during the test to determine the values I_1 e J_2 for which plastic deformations starts or it is reached the rupture of bituminous concrete [2].
The test apparatus applies to the specimen two distinct loading phases: a first hydrostatic and a following deviatoric until yielding or rupture of material.
During the hydrostatic phase the specimen is subjected to a stress status spherical characterised by $\sigma_1=\sigma_2=\sigma_3=\sigma_M$, imposing in this way the value of I_1 therefore positioning along the tri-sector line of the first octant of the space of the principal stresses.
In the deviatoric phase the specimen is brought to the chosen stress state, applying in general three different values of $\Delta\sigma_1$, $\Delta\sigma_2$ e $\Delta\sigma_3$.
Nevertheless, it is better to define a load history on the deviatoric plane, fixing $\Delta\sigma_2$ and controlling the remaining two tensions in order that the mean one is constant and equal to the level reached in the phase of hydrostatic load.
This is obtained introducing the α parameter that is constant during the all deviatoric phase, assuming values comprises between -0,5 and 1.0 defined before the execution of the test. The Lode parameter μ is also constant and proportional to the tangent of the angle θ through the track of the path of the load and the horizontal on the deviatoric plane.
The just described procedure comes from the application of the theory of continuous in bases of which it are interpreted the experimental data recorded during the trials.
This interpretation is conducted on the basis of the following parameters:

- $\sigma_M = \frac{1}{3} I_1$ *mean sigma*;
- $\sigma_d = \sqrt{2J_2}$ *deviatoric sigma*;
- $\varepsilon_{vol} = D_1$ *volumetric deformation*;
- ε_d *deviatoric deformation.*

Operatively, the variation of the parameters I_1, J_2, μ, as already highlighted, is obtained with triaxial proofs with mean tension variable performing for each of them, in order to investigate all the deviatoric plane,

several trials with μ variable so as to determine the corresponding value of the deviatoric tension of yielding/rupture σ_d.
These values, related to the α parameter, allow the determination of the yielding/rupture function of the bituminous concrete [7], [10]. In particular this function is defined by the functional relation:

$$\sigma_d = f\left(\sigma_M, \mu\right)$$

Which can be easily determined from the interpolating relations of the parameters σ_d and α or $\sqrt{2 J_2}$ and μ.
The yielding/rupture function can be graphically represented by means of the projection of the yielding/rupture curves defined at constant σ_M on the deviatoric plane.

BITUMINOUS CONCRETES TESTED

The investigation on the performance characteristics of a bituminous concrete with expanded clay in place of natural aggregates was the purpose of this study.
In particular, the features of two wearing course asphalts were assessed, the former being traditional, the latter SMA [1], [3], [4].

Traditional bituminous concrete

The traditional bituminous mix tested had the grading curve of Table 1.
A silica aggregate with an apparent absolute gravity of 2,71g/cm^3 was used, while the employed bitumen was a plain 70-100 with a Performance Grade SHRP (AASHTO Designation MP1) PG58-22, whose characteristics are included in Table 2; hydrated lime was used as filler.
Two admixtures were preliminarily arranged, M1, as reference, with only traditional aggregates, and M2, where 10% of aggregates weight was changed with structural expanded clay with an apparent absolute gravity equal to 1,20g/cm^3.

Table 1: Traditional bituminous concrete

UNI / ASTM Riddle or Sieve	Diameter (mm)	Passing (%)	Kind of Aggregate KA
UNI n.15	12,00	100	Silica
UNI n.10	8,000	85	"
UNI n.5	4,000	48	"
ASTM n.10	2,000	35	"
ASTM n.40	0,420	17	"
ASTM n.80	0,177	12	"
ASTM n.200	0,074	8	Hydrated lime
Plain bitumen 70/100 - see Table 2			

The Marshall stability examination on the specimens belonging to the two mixes showed an 18% increase in the performances for the M2 admixture, thanks to the addition of expanded clay; anyway, as already stated, the aggregates change involved a not negligible volumetric variation of the original grading curve as, the weight being unchanged, expanded clay occupied a larger volume than silica aggregates.
So as to rely upon trustworthy comparisons, volume changes of aggregates were considered and, as a matter of facts, two further admixtures, named M3 and M4 were prepared, with a volume change of aggregates with expanded clay equal to, respectively, 10% and 20%.
The particle size characteristics of the mixes are included in Table 3 from the point of view of retained quantities referred to 1kg of admixture.
The information found by expanded clay producers stated that, for a traditional bituminous concrete, every 5% addition of expanded clay in weight involves a bitumen increase equal to 0,5% [9], while this investigation found that, in case of volume addition of expanded clay, a lower bitumen quantity is needed, compared to a traditional admixture.

Table 2: Rheological characteristics of the bituminous binder used into the traditional concrete

BITUMINEN		70/100 PG58-22
Traditional parameters	Penetration at 25°	64 dmm
	Softening point (PA)	47 °C
	Penetration Index	-1,41
	Fraass failure point	-8°C
	Din. Viscosity at 60°C - $\dot{\gamma}$ =100 s^{-1}	19,45 Pas
	Din. Viscosity at 160°C - $\dot{\gamma}$ =100 s^{-1}	0.035 Pas
	Din. Viscosity at 60°C - $\dot{\gamma}$ =100 s^{-1} (post RTFOT)	35,08 Pas
	Residual penetration a 25°C (post RTFOT)	59,37 **%**
	PA variation (post RTFOT)	+ 4 °C
SHRP parameters	**BBR**	
	$S(t)_{60}$ T=**-12**°C	136 MPa
	m_{60}	0,44
	LST Temperature	-17 °C
	LmT Temperature	-25 °C
	DSR	
	G*/sinδ (T=**58**°C on plain bitumen)	1,87 kPa
	G*/sinδ (T=**58**°C, post RTFOT)	5,72 kPa
	G* · sinδ (T=**22**°C, post RTFOT+PAV)	3405 kPa
	Din.Viscosity at 135°C	0,08 Pas

Table 3: Traditional bituminous concrete

UNI / ASTM Riddle or Sieve	Diameter (mm)	Retained (g)							
		Admixture M1		Admixture M2		Admixture M3		Admixture M4	
		0% EC		10% EC weight		10% EC vol.		20% EC vol.	
		KAS	EC	KAS	EC	KAS	EC	KAS	EC
UNI n.15	12,00	-	-	-	-	-	-	-	-
UNI n.10	8,000	150,00	-	90,00	60,00	90,00	26,57	30,00	53,14
UNI n.5	4,000	370,00	-	330,00	40,00	330,00	17,71	290,00	35,42
ASTM n.10	2,000	130,00	-	130,00	-	130,00	-	130,00	-
ASTM n.40	0,420	180,00	-	180,00	-	180,00	-	180,00	-
ASTM n.80	0,177	50,00	-	50,00	-	50,00	-	50,00	-
ASTM n.200	0,074	40,00	-	40,00	-	40,00	-	40,00	-
Filler – Hydrated lime		80,00	-	80,00	-	80,00	-	80,00	-
PARTIAL RESULTS (g)		1000,00	-	900,00	100,00	900,00	44,28	800,00	88,56
TOTAL WEIGHT (g)		1000,00		1000,00		944,28		888,56	
∆ WEIGHT (%)		-		-		- 5,57		- 11,14	
∆ VOLUME (%)		-		+ 12,58		-		-	
KAS SILICA – Apparent Absolute gravity 2,71 g/cm^3									
EC EXPANDED CLAY – Apparent Absolute gravity 1,20 g/cm^3									

Indeed, the Marshall optimisation process of the bitumen percentage discovered that the higher the expanded clay quantity volume substitution, the lower the binder quantity which is to be added, as indicated in Table 4; this table also includes the mechanical features of the various mixes from the viewpoint of Marshall parameters and indirect tension resistance.
Table 5 condenses the triaxial mechanical parameters found by means of the UNIBAS M.P.T. apparatus for the admixtures named M1, M3 and M4, while Figure 1 includes the superposition of the failure curves of the three admixtures with the variation of the hydrostatic load mean sigma.
One could notice from Figure 1 that, for a traditional bituminous binder, labelled M1, a classic convex failure surface is experienced, while, for the expanded clay asphalts M3 (10%) and M4 (20%), some cusps are observed along the pseudo-compression axes.
This means that the behaviour in compression of the admixtures M3 and M4 is far better than the traditional bituminous mix one, the performances from the standpoint of shear and tension being substantially unaltered.
In addition, it is important to detect that, for low values of the mean sigma, the 20% volume expanded clay admixture (M4) showed the best performances, while for higher values M3 revealed as being the best mix.

The superficial features of the materials from the point of view of both micro and macro-texture were assessed on small asphalt laying, the resulting values of BPN and HS being included in Table 6.
The M4 admixture drove to a 16% increase of BPN, compared to ordinary bituminous concrete values.

Table 4: Optimal bitumen percentages and mechanical characteristics

Admixture	EC (%)	Bitumen (%)	Marshall Stability (daN)	Marshall Stiffness (daN/mm)	Residual voids (%)	Indirect tension strength at 25°C (daN/cm^2)
M1	0,00	5,9	1109	269	2,0	17,00
M2	10,0 Weight	7,0	1307	369	5,5	16,20
M3	10,0 Volume	5,6	991	248	3,0	15,80
M4	20,0 Volume	5,3	1428	376	4,5	15,90

Table 5: UNIBAS M.P.T. tests results

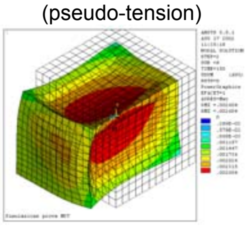
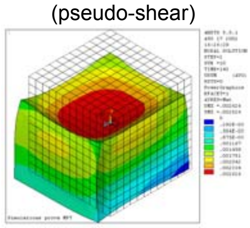
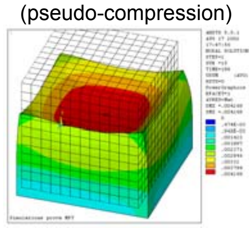
Admixture	Loading cycle α	σ_M (daN/cm^2)	σ_D (daN/cm^2)
M1	1	70,26	28,00
	0	70,26	46,52
	-0,5	70,26	66,41
	1	97,76	48.98
M3	1	70,26	21,02
	0	70,26	31,18
	-0,5	70,26	77,59
	1	97,76	48,81
M4	1	70,26	24,69
	0	70,26	32,20
	-0,5	70,26	84,21
	1	97,76	39,22
α=1 (pseudo-tension) 		**α=0** (pseudo-shear) 	**α=-0,5** (pseudo-compression) 
σ_M – Mean value of sigma σ_D – Deviatoric failure sigma value			

Table 6: Micro and macro-texture of admixtures

Admixture	EC (%)	Bitumen (%)	B.P.N.	HS (mm)	Macro-texture
M1	0,00	5,9	43,0	0,47	average
M3	10,0 Volume	5,6	47,0	0,63	average
M4	20,0 Volume	5,3	50,0	1,05	coarse
BPN – CNR B.U. n.105/85 HS – CNR B.U. n.94/83					

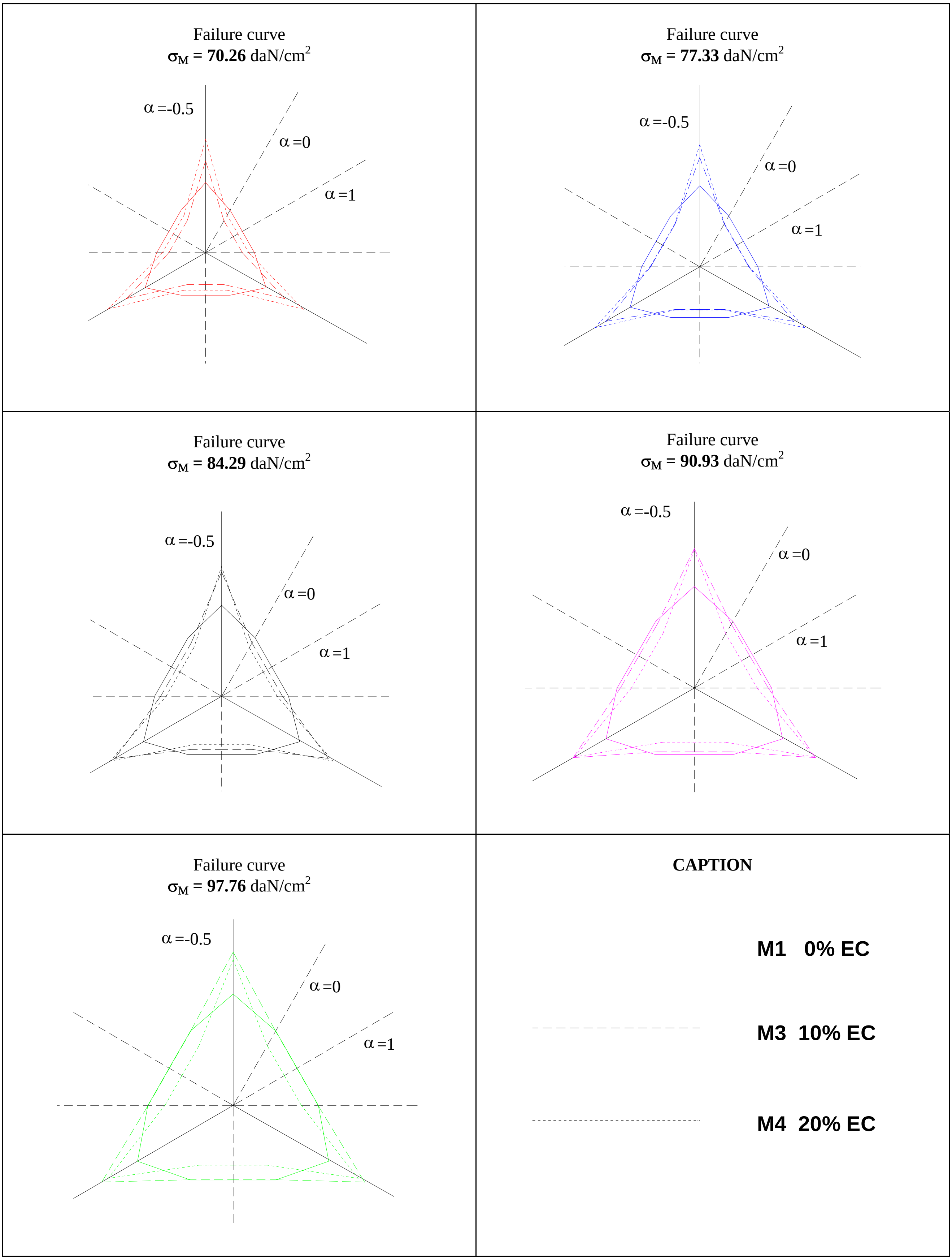


Figure 1: Failure curves in the Medhal plane

Stone Mastic Asphalt

The Stone Mastic Asphalt admixture analysed for the investigation was characterised by the grading curve of Table 7, with the following aggregates:

- basalt, with an apparent absolute gravity of 2,99g/cm^3, for the 12,70mm passing and 6,35mm retained fraction;
- limestone, with an apparent absolute gravity of 2,84g/cm^3, for the remaining fraction passing at the 6.35mm sieve and retained at the 0,074mm one.

A modified 80-100 bituminous binder was used with a Performance Grade SHRP (AASHTO Designation MP1) PG52-28, whose features are condensed in Table 8; as usual, hydrated lime was employed as filler.
The first mix, labelled SMA1, was manufactured only with natural aggregates, while in the second, SMA2, a 30% volume change of natural aggregates with structural expanded clay was adopted.

Table 7: SMA admixture

UNI / ASTM Riddle or Sieve	Diameter (mm)	Passing (%)	Kind of Aggregates AK
ASTM ½"	12,70	100	Basalt
UNI n.10	8,000	96	"
ASTM ¼"	6,350	68	"
UNI n.5	4,000	44	Limestone
ASTM n.10	2,000	26	"
ASTM n.40	0,420	14	"
ASTM n.80	0,177	12	"
ASTM n.200	0,074	11	Hydrated lime
80/100 Modified Bitumen: see Table 8 Stabilizer: Cellulose 0.3% on the aggregates weight			

Table 8: Rheological characteristics of the bituminous binder adopted into the SMA

	BITUMEN	80/100 M PG52-28
Traditional parameters	Penetration at 25°	55 dmm
	Softening point (PA)	72 °C
	Penetration Index	+ 3,50
	Fraass failure point	-15 °C
	Din. Viscosity at 60°C - $\dot{\gamma}$ =100 s^{-1}	27,13 Pas
	Din. Viscosity at 160°C - $\dot{\gamma}$ =100 s^{-1}	0,110 Pas
	Din. Viscosity at 60°C - $\dot{\gamma}$ =100 s^{-1} (post RTFOT)	39,06 Pas
	Residual penetration a 25°C (post RTFOT)	54,54 %
	PA variation (post RTFOT)	+ 7 °C
SHRP parameters	**BBR**	
	$S(t)_{60}$ T=**-12**°C	260 MPa
	m_{60}	0,35
	LST Temperature	-20 °C
	LmT Temperature	-22 °C
	DSR	
	G*/sinδ (T=**58**°C on plain bitumen)	1,46 kPa
	G*/sinδ (T=**58**°C, post RTFOT)	3,23 kPa
	G* · sinδ (T=**22**°C, post RTFOT+PAV)	1238 kPa
	Din.Viscosity at 135°C	0,25 Pas

The particle size characteristics of the admixtures can be found in Table 9 from the viewpoint of retained quantities, referred to 1kg of mix.
The bitumen percentage determination was carried out by means of the Marshall method, the results being 7,5% and 6,5%, respectively, for SMA1 and SMA2.

This result confirmed the assumption that, in presence of the natural aggregates volume substitution with expanded clay, the bitumen quantity needed is reduced, compared to the original mix (Table 10).

Table 9: SMA admixtures

UNI / ASTM Riddle or Sieve	Diametrer (mm)	Retained (g)					
		Admixture SMA1			Admixture SMA2		
		0% EC			30% EC vol.		
		KAB	KAC	EC	KAB	KAC	EC
ASTM ½"	12,70	-	-	-	-	-	-
UNI n.10	8,000	40,00	-	-	40,00	-	-
ASTM ¼"	6,350	280,0	-	-	180,0	-	40,40
UNI n.5	4,000	-	240,0	-	-	40,00	83,92
ASTM n.10	2,000	-	180,0	-	-	180,0	-
ASTM n.40	0,420	-	120,0	-	-	120,0	-
ASTM n.80	0,177	-	20,00	-	-	20,00	-
ASTM n.200	0,074	-	10,00	-	-	10,00	-
PARTIALI VALUES (g)		320,0	570,0	-	220,0	370,0	124,32
FILLER–HYDR. LIME(g)		110,00			110,00		
TOTAL WEIGHT (g)		1000,00			824,32		
Δ WEIGHT (%)		-			-175,68		
Δ VOLUME (%)		-			-		
KAB Basalt – Apparent absolute gravity 2,99 g/cm^3 **KAC** Limestone – Apparent absolute gravity 2,84 g/cm^3 **EC** Expanded clay – Apparent absolute gravity 1,20 g/cm^3							

Table 10: Optimal bitumen percentages and mechanical characteristics

Admixture	EC (%)	Bitumen (%)	Marshall Stability (daN)	Marshall Stiffness (daN/mm)	Residual voids (%)	Indirect tension strength at 25°C (daN/cm^2)
SMA1	0,00	7,5	1513	456	3,8	18,00
SMA2	30,0 Volume	6,5	1604	398	3,9	18,50

After accurate considerations, the Authors decided to substitute with expanded clay just a limited quantity of the 6,35-8,00mm basalt, the large change being demanded to the limestone quantities (4,00-6,35mm).
Indeed, notwithstanding the good mechanical performances of structural expanded clay, the basalt aggregates would guarantee far better results.
As a matter of fact, the tendency to material costs saving should take into account the fact that, for SMA admixtures, the high performances of the aggregates skeleton significantly influence the overall mechanical properties of the road pavement, the aggregates substitution being, therefore, just limited to the weaker materials (limestone), as indicated in Table 9, because of its reduced performances from the viewpoint of wear and tear and abrasion.
The mechanical characterisation allowed the Authors to state that SMA1 and SMA2 (30% expanded clay volume change) admixtures exhibited similar performances, as explained in Table 10.
This outcome was confirmed by the triaxial UNIBAS M.P.T. mechanical characterisation results of Table 11.
Moreover, from the point of view of superficial characteristics, the latter revealed a slightly higher BPN value.
This consideration took into account the fact that, at the very beginning, the BPN values of SMA admixtures are negatively influenced by the bitumen patina covering the aggregates skeleton, because of the high required percentage of the bituminous binder itself.
Thus, after a short initial period, the cars tire actions of the surface positively influences the micro-texture, the BPN values being therefore not jeopardised.
So as to simulate the trustworthiness of this assumption, some sandblasting and scratching out actions were performed, in order to evaluate the incremental variation of macro-texture (see Table 12): in this way, final values of 56 and 65 for the SMA1 and SMA2 BPN values were measured, the improvements being, respectively, 40% and 51% [(1)].

Table 11: UNIBAS M.P.T. tests results

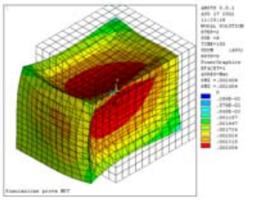
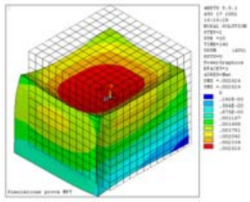
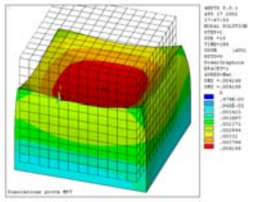
Admixture	Loading cycle α	σ_M (daN/cm^2)	σ_D (daN/cm^2)
SMA1	1	70,26	36,62
	0	70,26	47,20
	-0,5	70,26	121,78
	1	97,76	55,82
SMA2	1	70,26	37,42
	0	70,26	44,81
	-0,5	70,26	115,68
	1	97,76	59,70
α=1 (pseudo-tension) 		**α=0** (pseudo-taglio) 	**α=-0,5** (pseudo-compression) 
σ_M – Mean value of sigma			
σ_D – Deviatoric failure sigma value			

Table 12: Micro e macro-texture of admixtures

Admixture	EC (%)	B.P.N. Initial	B.P.N. final	HS (mm)	Macro-texture
SMA1	0,00	40	52	0,98 [1]	coarse
SMA2	30,0 Volume	43	65	0,93	coarse
BPN – CNR B.U. n.105/85					
HS – CNR B.U. n.94/83					

CONCLUSIONS

The Authors investigated the use of structural expanded clay for traditional close matrix bituminous concrete and SMA, a percentage of original aggregates within 10 and 30% in volume being changed with the just mentioned lightweight material.

The volume substitution, rather than the weight one, found its reason in the fact that the apparent absolute gravity of such an artificial material is significantly lower than the corresponding value of conventional natural aggregates.

As a matter of fact, a weight substitution of natural aggregates with expanded clay would involve the use of higher quantities of aggregates, the overall comparison between the two different admixtures being, as a consequence, irrecoverably jeopardised.

The analysis covered the assessment of both mechanical and surface properties, highlighting the improvements in the overall performance of ordinary and SMA mixes, condensed below for the sake of brevity:

- considerable weight saving of precious aggregates (basalt, silica) can be achieved;
- the higher the volume percentage of aggregates substituted, the higher the bitumen quantity saving;
- no changes are experienced in Marshall stability;
- no variations are measured for the indirect tension resistance;
- the psedo-compression performances, from the standpoint of failure domains are far better than the corresponding values measure for natural aggregates-based admixtures, the pseudo-tension and shear characteristics being unaltered;

- increase in the surface characteristics of the pavement from the point of view of micro and macro-texture, with a consequent improved safety level for users, because of the higher grip available.

Finally, it is possible to state that the use of expanded clay in a bituminous concrete can positively influence both the mechanical and the surface characteristics of the pavement, involving, at the same time, significant environmental benefits belonging to the reduced quantity of natural aggregates used for the purpose.

NOTES

(1) The value HS = 0,98 was obtained from a laboratory laying prepared by means of a static roller compactor and applying a compaction energy which would avoid separation phenomena. This procedure was in compliance with the current technical literature which states that, for SMA pavements, low energy traditional compaction techniques are to be used.

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