Non - Structural Lightweight Concrete Produced with Volcanic Scoria from São Miguel Island

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Acronyms

BTC – Bagacina Traditional concrete
BUC – Bagacina Uno concrete
CBA - Coarse bagacina aggregate;
CECA - Coarse expanded clay aggregate;
CLA - Coarse bagacina aggregate;
CS - Coarse natural sand;
ECA – Expanded clay aggregates (Leca);
FBA - Fine bagacina aggregate;
FECA – Fine expanded clay aggregate;
FS - Fine natural sand;
LBS – Lightweight bagacina screed
LLS - Lightweight Leca screed
LTC – Leca M Traditional concrete
LUC – Leca Uno concrete
LWC - Lightweight concrete
LWA - Lightweight aggregates;
LWSA - Lightweight scoria aggregates;
NA - Normal weight aggregates;
NSLWC – Non-structural lightweight concrete;
NWC - Normal weight concrete;

Introduction

The density reduction (under 2000 kg/m^3) and better thermal insulation features (thermal conductivity, usually lower than 1,0 w/m^{0}C) make the use of LWA in concrete emerge as a potentially advantageous alternative compared to NWC, especially in areas where these properties are crucial. The NSLWC is usually produced with artificial aggregates such as expanded clay, expanded polystyrene (EPS) or cork particles. Nevertheless, the production of these aggregates is associated with a high cost due to their energy consumption during the manufacture process. Therefore is important to find more economical solutions and natural lightweight aggregates might be advantageous, due to the reduced cost of extraction. The main properties which distinguish NSLWC, are its low density and low compressive strength, typically less than 10 MPa.

Reducing the density means the increase in volume of voids on the concrete structure, which can be achieved by changes in the mortar (introducing air), in the aggregate type or both (Bogas 2011). Three distinct production techniques are used in LWC: "no-fines concrete"; "cellular concrete" and "concrete with lightweight aggregates".

This paper aims to study and characterize the mechanical and physical behavior of non-structural lightweight concrete with volcanic scoria aggregates originated from the Azores, Portugal. The dry density, compression and tensile strength, elasticity modulus, dry shrinkage, capillary absorption, thermal conductivity and behavior of concrete when subjected to high temperatures were analyzed and the results were compared to others types of concretes commonly used in non-structural applications.

1. Experimental program

1.1. Materials and methods

The experimental program involved the characterization of volcanic scoria aggregates, commercially designated as “bagacina”, well as the non-structural concretes made with this material. In order to compare and facilitate the analysis of the mechanical properties from concretes with LWSA, were also produced others types of concretes commonly used in non-structural applications.

The scoria aggregates from São Miguel (Azores) were obtained through the screening, milling and separation of material taken from natural deposits. The values of particle dry density (ρ_p) 24 hours water absorption ($wabs_{24h}$) crushed strength and sieve size fraction are show in Table 1. This aggregate is composed by coarse (CBA) and fine aggregate (FBA). It were also used expanded clay aggregates, designated as "Leca M" into the production of NSLWC.

Due to the small number of research about NSLWC, it was decided to search for products widely known on the market, so it could be recreated with scoria aggregate.

Two types of concrete were produced: “Traditional Solution”, “Uno Solution” and also a lightweight screed. The "Traditional Solution" consists of a pervious concrete, Above this solution, is usually applied a lightweight screed finishing. The second solution consists on a ready concrete mixture with higher compactness and higher cement paste dose, releasing the placement of a screed layer. The lightweight screed was produced in order to replace the current screeds, which are produced with normal-weight aggregates. Consist of a solution of greater compactness than Uno Solution, due to the higher dosage amount of cement paste and fine aggregate and sand.

Table 1 - Aggregate properties

Property	Natural aggregates			Artificial aggregates	
	CBA 1	CBA 2	FBA	CECA	FECA
Sieve size fraction (di/Di)	4-11,2	1-8	0,5-4	8-11,2	4-8
Particle dry density, ρp (kg/m^3)	1671	1844	1904	603	627
Loose bulk density, ρb (kg/m^3)	810	1048	1166	334	350
24 h water absorption, w_{abs24h} (%)	9,2	3,4	3,7	18,4	18
Crushing strenght (MPa)	3,6	6,4	-	1,4	1,4

1.2. Mix proportions and concrete mixing

The formulation of LWSA concretes took into account the composition of the solutions Leca, in order to try to obtain similar compositions. All the concrete compositions are listed in Table 2. The effective water/cement ratio (w/c) concerns the effective water available for cement hydration, which means that does not include the water absorbed by aggregates.

Table 2 - Mix proportions and fresh concrete density

Mixes	BTC	LTC	*Betespuma*	BUC	LUC	*Betnível*	LBS	LLS
CBA1 (l/m^3)	583$^{a)}$	-	210$^{c)}$	-	-	210$^{c)}$	-	-
CBA2 (kg/m^3)	-	-		540	-		-	-
FBA (kg/m^3)	-	-		371	-		725	-
ECA (kg/m^3)	-	583$^{b)}$		-	390		-	324$^{d)}$
CS (kg/m^3)	-	-		-	-		47	48$^{e)}$
FS (kg/m^3)	-	-		-	-		409	408
effect water (l/m^3)	60		90-120	150		200-220	180	
Cement (kg/m^3)	150		250	130		350	240	
Filler (kg/m^3)	-		-	280		-	180	
$a_{efectiva}$/l	-		-	0,37		-	0,43	
effect w/c	0,4		0,36-0,48	1,15		0,57-0,63	0,75	
Fresh density, ρ_f (kg/m^3)	1156	601	473	1549	1000	634	1670	1368
Total void ratio (%)	34,8	33,4	-	20,1	16,9	-	13,8	10,7

$^{a)}$ l/m^3

$^{b)}$ Leca M aggregates l/m^3

$^{c)}$ EPS aggregates l/m3

$^{d)}$ Leca M, S and XS aggregates l/m3

$^{e)}$ Fine gravel

1.2.1. Tests and curing process

Different types of tests were performed on hardened state with the aim of physical, mechanical and durability of concrete characterization. The list of tests and their specifications documents, along with the curing conditions are presented in Table 3.

Table 3 - Tests on hardened state concrete and curing conditions

Test	Mold	Dimensions (cm)	Number of specimens	Specification document	Curing conditions
Compressive strength	Cubic	15x15x15	10/13[a]	EN 12390-3	Water cured during 28 days
Tensile strength	Cylindrical	Ø 15x30	3	EN 12390-6	Water cured during 28 days
Modulus of elasticity	Cylindrical	Ø 15x30	3	LNEC E397	Water cured during 28 days
Punching shear strength	Slab	25x25x10	12	Adapted procedure from ICIST report EP nº10/2007	i) Water cured during 7 days; ii) Drying chamber durind 21 days.
Drying shrinkage	Prism	30x30x10	2	LNEC E398	Drying chamber during 90 days
Capillary absorption	Cylindrical	Ø 15x15	2	LNEC E 393	i) Water cured during 14 days; ii) Ventylated oven 60±5ºC, during 14 days
Water permability	Cylindrical	Ø 15x5	2	Adapted from Bogas (2011)	Water cured during 28 days
Thermal conductivity	Cylindrical	Ø 15x5	3	Adapted procedure from Isomet 2114 instructions	Water cured during 28 days
Behaviour of concrete subjected to high temperatures	Cubic	15x15x15	25	ASTM E119-005a; LNEC E364.	i) Water cured during 28 days; ii) Drying chamber durind 90 days.

[a] 13 specimens for Uno type concrete

Drying chamber - Relative humidity of 50±5% and temperature of 22±2ºC

1.2.2. Punching shear resistance

It's important to verify that the concretes produced meet the minimum requirements in terms of tensile strengths according to UPEC classification (LNEC 1996). Thus it's compared the strengths of each respective class of concrete, with the minimum allowable stresses of each class. Specimens were made with dimensions of 25 x 25 x 10 (cm).

Table 4 – Punching shear classes defined in UPEC specification

	P_2	P_3	P_4	P_{4s}
Concentrated load (kgf)	100	200	500	1000
Tension (MPa)	2	3	4	5
Diameter of the area loaded (cm)	2,52	2,91	3,99	5,05

The slabs were tested without being demolded, with the aim of minimizing the possible disintegration of the concrete, especially in the inferior layers of traditional solutions. The samples sat on a metal plate on the underside of the press, while discs were placed in the center of the slabs, simulating each of the categories P (Figure 1).

Figure 1 - Example of a punching shear test

1.2.3. Drying shrinkage

The total axial shrinkage was determined by a demountable mechanical strain gauge (DEMEC) with a precision of 1 µm and a gauge length of 5 mm. The DEMEC was placed over two steel pins, 200 mm apart, which had been glued onto one of the concrete's molded surfaces.The total shrinkage of each specimen was measured between 24 hours and 91 days.

1.2.4. Capillary absorption

This test consists of determining the water absorption rate (sorptivity) of concrete by measuring the increase in the mass of a specimen due to absorption of water as a function of time when only one surface of the specimen is exposed to water. The exposed surface of the specimen was immersed in 5±1 mm of water and the mass of the specimen was measured after 10, 20, 30, 60 minutes and 3, 6, 24 and 72 hours after the initial contact with water. During the test, the specimens were covered with a bell-glass in order to avoid the water evaporation. The water absorption was calculated for each age and the absorption coefficient was obtained from the slope of the linear regression line between $\sqrt{20}$ min and $\sqrt{6}$ hours, following the theoretical deduction by Kropp et al 1995. This relation however cannot, be applied in the early hours of the test because for more advanced time, there is a slowing of the rate of wicking due to the increase of the water content inside the specimen.

1.2.5. Water permeability

The test consisted in applying a pressure to the entrance of the saturated sample in order to obtain a flow of water in approximately steady and laminar, allowing determination of the time that the water that passed through the specimen, took to fill a given volume, in order to calculate the flow rate drained and consequently the permeability coefficient, k_w. The equipment (Figure 2) consisted of placing the specimen in the test area, with rubber rings on top and bottom, to prevent any leakage of water. In the lower part of the specimen, were placed containers to thereby collect and measure the volume of water.

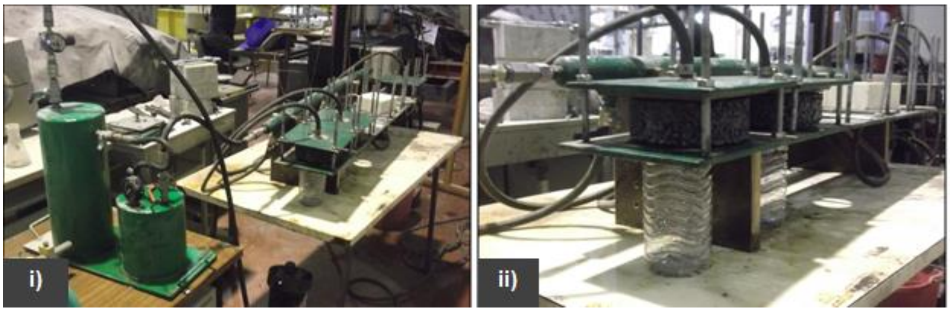

Figure 2 - Water permeability test. i) Equipment; ii) Detail of the specimen and container

1.2.6. Behavior of concrete subjected to high temperatures

The exposure test of concrete at high temperatures and their subsequent characterization regarding their residual strength was fulfilled for all samples except the Lightweight Screeds. The residual compressive strength was measured after the exposure at different temperature stages, T200, T400, T600 and T800, which corresponds to a maximum exposure temperature around 60 minutes. The temperature increased, at a rate of 2-3,5 ºC/min. In order to monitorize the evolution of the temperature inside the specimens when exposed to high temperatures, type K thermocouples were introduced inside them. After the curing process, the specimens were heated in an electric furnace at the temperatures mentioned above. After the trial, the specimens were cool off naturally at the room temperature for 1 day and then relocated to a dry chamber (temperature 20±2 ºC; relative humidity of 50±5%).

2. Results and discussion

All test's results, are listed in Table 5 for each composition. Results of punching shear resistance are explained further ahead at §2.5.

Table 5 – Detailed result's list for each concrete

Properties		**Traditional Solution**			**Uno Solution**			**Lightweight Screed**	
		Bagacina	**Leca**	**EPS**	***Bagacina***	**Leca**	**EPS**	***Bagacina***	**Leca**
Dry density ρ_d (kg/m^3)		1080	510	350	1360	870	460	1600	1250
$f_{cm,28d}$(MPa)		1,6	1,7	0,5	5	5,3	1,3	5,5	9
$f_{ctm,28d}$ (MPa)		0,2	0,5	0,1	0,7	0,5	0,3	0,6	1,0
$E_{c,28d}$ (Gpa)		3,3	1,9	-	6,8	4,9	-	15,5	14.6
Drying shrinkage (x10^{-6})		-575	-795	-3500	-750	-815	-3500	-565	-620
Capilary absorption	**Abs_{24h} (Kg/m²)**	Not tested			14,24	15,33	8,18	12,36	13,11
	C_{abs} (x10^{-3} mm/min^{0,5})				0,336	0,501	0,146	0,234	0,269
Permeability, kw (x10^{-3} m/s)		82,22	82,85	54,62	0,16	5,48	1,37	6,56	0,20
Thermal conductivity, λ (W/mºC)		0,22	0,11	0,07	0,40	0,23	0,10	0,63	0,63
Residual compressive strength	**20ºC**	1,6	1,3	0,7	6,9	5,8	1,6	Not tested	
	200ºC	1,4	0,8	0,4	6,6	5,3	1,2		
	400 °C	1,1	0,7	0,3	6,4	4,5	0,9		
	600 °C	0,8	0,6	Spalling	4,7	3,8	Spalling		
	800 °C	0,5	0,5		3,6	2,8			

2.1. Concrete dry density

As expected, the concrete dry density was higher with scoria aggregates, which is justified by the density of these aggregates (Table 5). The use of LWSA led to concrete with dry densities of about 110%, 60% and 30% higher than the other solutions with Leca aggregates, respectively Traditional Solution, Uno Solution and lightweight screed, and approximately 200% higher compared to cellular concrete with EPS. Considering the density of classes as defined in EN 206, scoria concrete can be fitted in classes between D1.2 and D1.6. About the remaining compositions, only LUC (D1.0) and LLS (D1.4) presented dry density values over 800 kg/m^3, which is the minimum defined in EN 206. The use of LWSA in non-structural concretes increases at least one level its density class, when compared with existing solutions with expanded clay aggregates.

2.2. Compressive strength

The use of LWSA, despite the superior density and crush resistance, does not contribute to an increase in the compressive strength. In the “Traditional Solution” the predominant mode of failure coincided with the disintegration of particles (Figure 3), despising aggregate’s crushing resistance. This occurs due to the fact that these concretes consists, on a agglomerate of particles bonded by a weak cement paste.

Figure 3 – BTC after compressive strength test

Regarding “Uno Solutions”, it is again verified that resistances are identical which is justified by the higher volume of voids in concrete with bagacina, because of the inherent difficulties involved in their molding and finishing. Rupture of concrete with Leca was conditioned by the aggregate, as opposed to Bagacina Uno, whose rupture surface crossed the paste, leading to early breakdown between particles, without the maximum load capacity of the aggregates was mobilized (Figure 4).The fact that the LWSA are connected by small spots of paste, because of their angular shape, which difficult the compaction resulting in increasing void percentage of the matrix, facilitated the development of rupture surfaces around the aggregate particles.

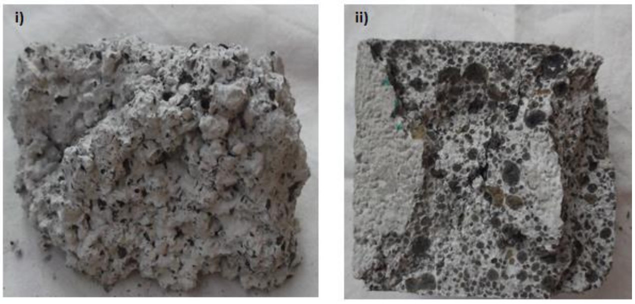

Figure 4 - Specimens “Uno Solutions” after rupture. i) Bagacina Uno; ii) Leca Uno

The high heterogeneity reached on the LBS specimens, resultant of the difficulties inherent to its compaction and finishing (Figure 5), did not allow the accurate characterization of its strength, leading to values that underestimate its actual capacity. The specimens were tested perpendicular to the direction of concreting, so it’s created an imbalance in the stress field, causing the specimen to break eccentrically in the zone of lower compactness. In consequence, the greater homogeneity of LLS (Figure 5) resulted in an increase of strength compared to LBS.

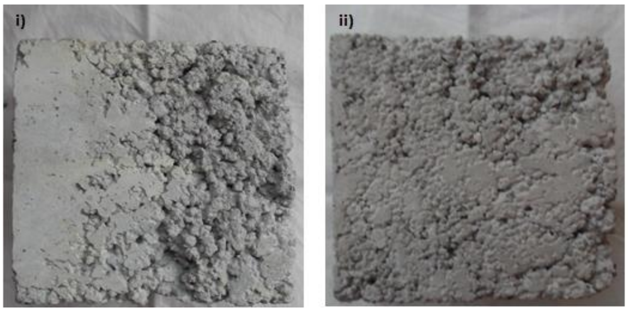

Figure 5 – Specimens “Lightweight aggregate screed” i) with bagacina; ii) with Leca

2.3. Tensile strength

Tensile strength of the solutions with LWSA were higher than the other concretes, due to higher resistance capacity of their aggregates. In "Traditional Solutions" rupture occurred by particles disintegration.On the various concretes, lightweight screed and Uno Solutions, the rupture surface crossed the particles, indicating the strong dependence of the tensile strength on the capacity of the aggregate (Figure 6). For this reason, it would be expected that the concrete formulated with LWSA presented a higher tensile strength. However, this was not observed, due to the problems already mentioned, about the concrete compaction. For this reason the results obtained for the tensile strength doesn't reflect accurately the actual capacity of the concrete.

Figure 6 - Detail of the surface rupture (LUC) after tensile strenght test

2.4. Modulus of elasticity

The incorporation of LWSA with greater rigidity than the expanded clay aggregates (Leca), allowed to obtain concretes with a higher modulus of elasticity, 75% in Traditional Solution and 40% in Uno Solution. According to EN 13813, BUC and LBS can be fitted in classes E5 (5 GPa) and E10 (10 GPa), respectively. It is also usual to relate the modulus of elasticity and the compression strength cylinder ($f_{cm,cil28}$) as shown in Figure 7.

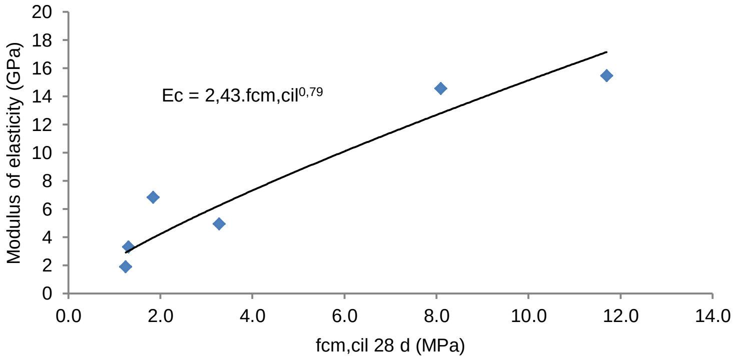

Figure 7 - Relation between modulus of elasticity and compressive strength measured in cylinders

2.5. Punching shear strength

Regarding punching resistance, it stands out the least positive behavior from the system with EPS (*Betnível*), not meeting the minimum strength requirements defined in UPEC classification, except for the P_2 class. The remaining concretes have met the minimum values, and the ones incorporating LWSA presented a better performance than Leca.This is justified because the rupture modes involved the tensile strength of concrete or crushing of aggregate particles, thus mobilizing its bearing capacity and also due to the fact that lightweight screed had a reduced thickness, facilitating their compaction, which led to a lower void volume and hence increased punching resistance of *bagacina's* solutions.

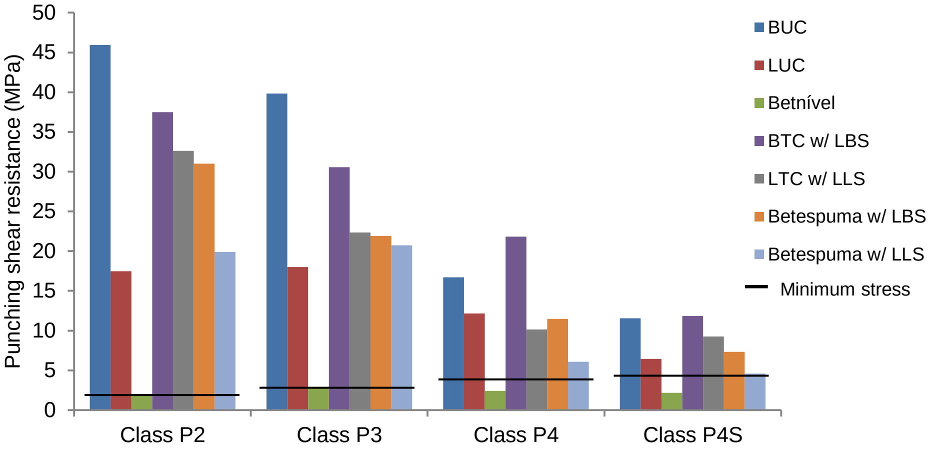

Figure 8 – Punching shear resistance

2.6. Drying shrinkage

Generally the lightweight concrete are characterized by less shrinkage in young ages and higher in long-term. This can be explained by the internal curing effect provided by the porous aggregate that can act as internal water reservoirs during the early ages (Holm and Bremner 2000, Neville 1995). As expected, the incorporation of LWSA leads to a lower long-term shrinkage than that of LWC with expanded clay aggregates of similar composition. The higher stiffness of CBA and FBA contributed to a shrinkage reduction after 90 days approximately of 30% (Traditional Solution) and 10% (Uno Solution and Lightweight screed).

Both Traditional and Uno Solutions had a similar behaviour, which means that BUC presented smaller values than LUC (Figure 10).Regarding lightweight screed, LBS registered values inferiors to LLS, due to the same reasons mentioned above, however LLS, presented an unjustified increase from the fifth day (Figure 11). Noteworthy is the fact that the cellular concrete with EPS, present much higher shrinkage compared to other concrete with lightweight aggregates. However it is noted that the values substantially higher in these mixtures are often observed and reported on real situations. This is justified from the type of aggregate used (EPS) present a very low stiffness, offering weak opposition to this type of concrete shrinkage (Figures 13 and 14). This phenomenon is aggravated by the fact that these concretes are produced with a high volume of low stiffness mortar since it is incorporated a high void volume.

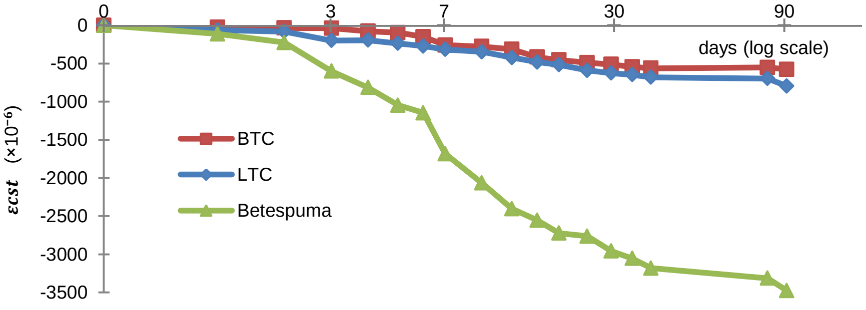

Figure 9 - Drying shrinkage until 90 days for Traditional Solutions

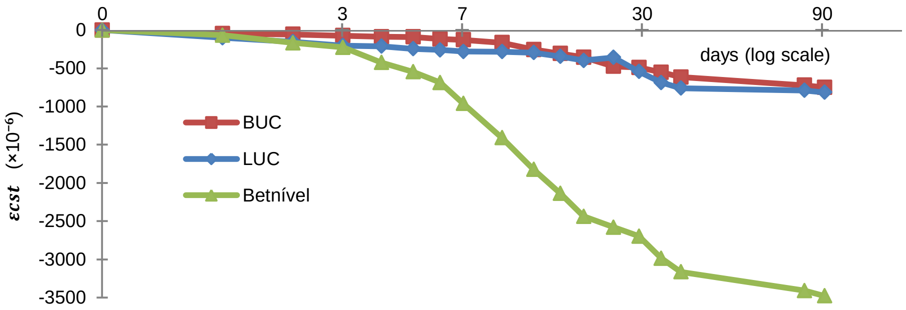

Figure 10 - Drying shrinkage until 90 days for Uno Solutions

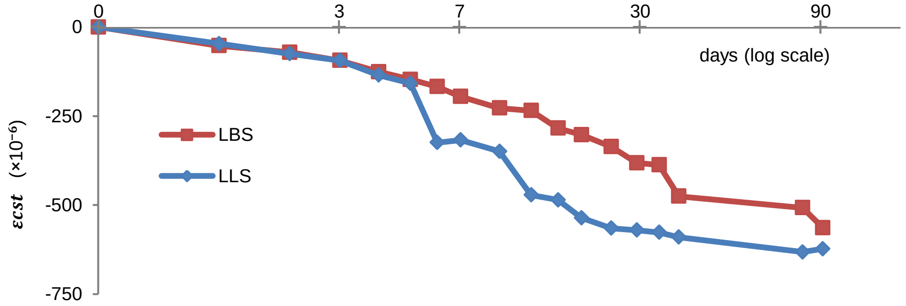

Figure 11 - Drying shrinkage until 90 days for Lightweight Screed

2.7. Capillary absorption

The capillary absorption coefficient was higher in concrete with the incorporation of Leca aggregates, which was expected given the high open porosity of these aggregates. Still, LUC has lower absorption capacity in the early stages due to the higher density of the protective layer existing in Leca particles which delays absorption.

The high absorption achieved in concretes with LWSA and Leca aggregates, can also be justified by the fact that the LWA exposed in the bottom surface of the specimens allow the easy access of water through the whole section of the concrete sample.. According to Costa (2011), concretes with EPS aggregates are less absorbent than other LWC. This aspect is confirmed due to reduced absorption capacity of Betnível (Figure 12) as the voids introduced in the mortar of this type of concrete, limit the capillary action, reducing the suction action. In fact, the system consists in successive narrowings and extensions of capillaries which reduce the capillary action. Only the cellular concrete with EPS obtained coefficients (C_{abs}) below 0,2 mm/min^{0,5} which means that the others specimens can be qualified as reduced durability concrete according to Browne (1991).

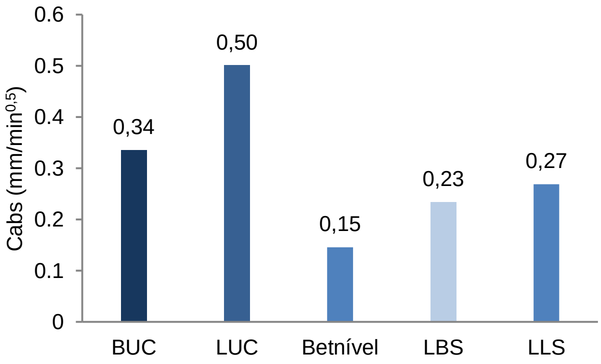

Figure 12 - Capillary absortion coeficient

2.8. Water permeability

In the test of water permeability, the behavior of the concrete was dependent on the type of aggregate and compactness of the mortar, ie, the void content and the quality of the paste that surrounds the aggregates. As reported by other authors (Sata et al. 2013, Tho-in et al. 2012, Zaetang et al. 2013), the water permeability varies exponentially with the total volume of voids in the concrete. Taking into account the concrete produced was possible to define an exponential regression curve which represents the relation between water permeability and void ratio (Figure 13). Pervious concretes such as BTC and LTC presented very high permeability values because of the porous structure of these concrete that allows the free passage of water flow. It would further be expected that the Uno Solutions and mixtures of bagacina had greater permeability. However, the opposite was found, which is justified by the high susceptibility to small differences in the test composition, compactness and variety of specimens.

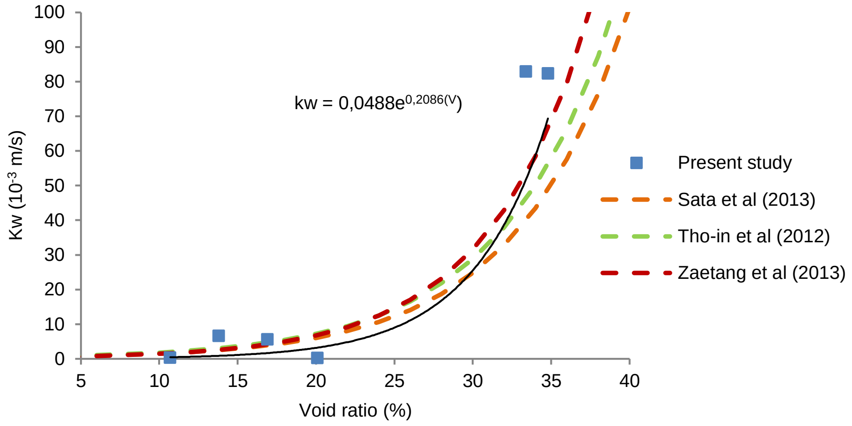

Figure 13 - Relationship between water permeability coefficient and total void ratio

2.9. Thermal conductivity

The coefficients of thermal conductivity are in the range of values for LWC according to Newman 1993 (0,2 - 1. W/m.ºC) and are lower in concrete of lower density and therefore greater void volume. The solutions with EPS achieved values of less than 0,10 W/mºC, whereas in concrete with LWSA the minimum was 0,22 W/m.ºC. Regarding the concrete types BTC and BUC, they presented values superior to compositions with Leca (about double), which is justified, given that aggregates are less porous and concrete has a higher density. The solutions that have the highest results are the lightweight screeds due to greater compactness and density. In this case, contrary to what would be expected, there are the same coefficients in both types of screeds.

2.10. Behavior of concrete subjected to high temperatures

Regardless of the type of solution was observed an improved performance of concretes with LWSA when subjected to high temperatures. The best results regarding the residual compressive strength corroborate, in general, the visual analysis of the concrete after thermal exposure. For this results must have contributed the least development gradients of temperature and humidity, as well as greater tensile strength capacity of concrete with higher density. Results indicate that the increase of temperature caused a general decrease in the residual compressive strength.

After interpreting Figure 14, contrary to what would be expected, there was major drop in the residual compressive strength of LTC (38,5%) compared to BTC (12,5%) after 200ºC. Three factors may have contributed to this occurrence : the greater effect of temperature gradients generated in LTC leading to higher temperatures inside; the higher initial moisture content present in the LTC; the higher tensile strength and better connection paste-aggregate in BTC whose surface porosity of its particles is higher, reducing the impact of the loss of cohesion between particles. The difference in the evolution of residual strength between BTC and LTC is higher at 200 ºC and superior to traditional 200 ºC (30%), and decreases progressively to about 5% (at 800 ºC).

Regarding Uno Solutions it was verified that BUC revealed a superior behavior, being able to assign the same reasons described above. Resistance compressive strength evolution is quite similar to both BUC and LUC, except in the 400 °C which differ by about 15%, with BUC resistance remaining virtually unchanged. Still, any of the solutions could ensure residual resistances up to 65 to 70% at 600 °C temperature. Cellular concrete with EPS particles suffered the most significant loss of compressive resistance to temperatures exceeding 400 °C (about 50 ± 5%), disintegrating completely for temperatures above 600 °C.

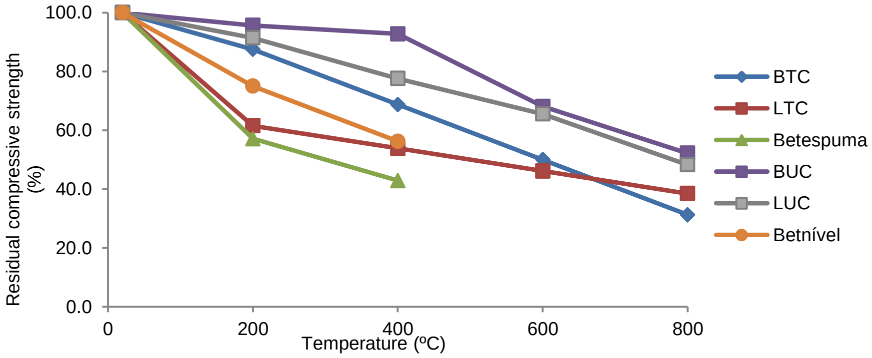

Figure 14 – Relative residual compressive strength

3. Conclusions

In the present study, the mechanical behavior of non-structural lightweight concrete produced with natural scoria from Azores (*bagacina*) was analyzed. The following main conclusions have been established:

- It was possible to produce NSLWC with natural scoria aggregates with density classes from D1.2 to D1.6;

- The use of LWSA, despite the superior density and crush resistance, didn't contribute to an increase in the compressive and tensile strength, but in real applications it can be higher, because of the problems faced in this study, associated to compaction;

- The use of LWSA with greater rigidity than the expanded clay (Leca), allowed to obtain concrete with a higher modulus of elasticity, 70%, 40% and 6% for BTC, BUC and LBS respectively. According to EN 13813 BUC and LBS can be featured in the classes E5 and E10.

- LWSA concretes showed a better performance than Leca, in punching shear test. This is justified because of the failure modes involve the tensile strength of concrete or crushing of aggregate particles thus mobilizing its bearing capacity and also due to have a reduced screed thickness, facilitating their compression, which led to a lower void volume and hence increased punching resistance on the part of bagacina solutions.

- The long-term shrinkage decreased when expanded clay aggregate were replaced by LWSA.

- The coefficient of absorption of concrete with the incorporation of Leca was higher than LWSA, namely 50% and 15% higher than BUC and LBS. Contrary to what happened with LWSA, Leca's concretes had lower absorption capacity in the early stages due to the higher density of the protective layer existing in Leca particles which delayed absorption.

- Traditional Solutions evidenced the higher water permeability,8 cm/s, because of their porous nature. It would be expected that the Uno Solutions and concrete made with LWSA had greater permeability. However, the opposite was found, which is justified by the high susceptibility to small differences in the test composition, and variety of specimens.

- Thermal conductivity coefficients obtained are in the range of values for LWC (0,2 - 1. W/m.ºC) and decreases with the lower density and therefore greater void volume of concrete. Solutions with EPS achieved values of less than 0,10 W/mºC, whereas in concrete with LWSA the minimum was 0,22 W/m.ºC.

-The results obtained after exposure to high temperatures, reveal that compressive strength reduces progressively with temperature increase. Generally the concrete with LWSA have lower resistance reductions, with particular emphasis on the BUC as the compressive resistance at 400 °C remained almost unchanged. It should be noted that concretes type BUC and LUC ensured residual resistances up to 65 to 70% at 600 °C temperature.

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