BETOANE UȘOARE OBȚINUTE DIN AGREGATE PUZZOLANICE. O ABORDARE TERMODINAMICĂ
THE LIGHTWEIGHT CONCRETE BASED ON POZZOLAN AGGREGATE . THERMO MECHANICAL EXPERIMENTAL APPROACH

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The present work focuses mainly on the thermo mechanical experimentation of different samples of lightweight concrete with different compositions and cement dosages.

The use of pozzolan in the compositions of lightweight concrete in the form of aggregates constitutes the essence of granular skeleton of the concrete.

The physico-mechanical modelling and thermal energy of porous media is adopted for predicting the apparent thermal conductivity.

The samples of lightweight concrete based on pozzolan subsequently underwent tests and mechanical resistance stresses. The results allowed the evaluation and assessment of the performance of this material giving it a mechanical strength conforms to the standards.

It is worth mentioning that the experimental measurements of the apparent thermal conductivity were performed on all the samples to be compared to the theoretical values.

Now this building material has interesting thermal and mechanical properties. Its use in the habitat and engineering structures offer significant benefits to economic, ecological, thermal and energetic.

Keywords: *Lightweight concrete, Pozzolan concrete, Porous materials, Compression strength, Thermal conductivity, Aggregates of pozzolan, Thermal insulation, Modeling, Building*

Nomenclature

Φ_{fd} : Flow of conduction; [W]
Φ_{icf} : Incoming conduction flow; [W]
Φ_{ocf}: Outgoing conduction flow; [W]
S_{ENG}: Quarry sand
S_{PZ}: Sand pozzolan
ε : Porosity
α : Compacitness
λ : Thermal conductivity; [W/m.K]
λ_{app}: Apparent thermal conductivity; [W/m.K]
λcopper: Copper thermal conductivity; [W/m.K]
λ_m: Measured thermal conductivity; [W/m.K]
$\lambda_{Parallel}$: Thermal conductivity of parallel model; [W/m.K]
λ_{Series}: Thermal conductivity of series model; [W/m.K]
λ_f : Thermal conductivity in fluid phase (air) ; [W/m.K]
λ_s: Thermal conductivity of solid matrix; [W/m.K]
θ: volume fraction of the portion arranged in parallel or series in the mixed model
ρ_{app} : Apparent bulk density; [kg/m^3]
ρ_{ag} : Absolute bulk density of grains; [kg/m^3]
$\frac{A}{S}$: $\frac{\text{Aggreagate}}{\text{Sand}}$: The ratio
BGPZ: Concrete pozzolan containing pozzolanic aggregate and quarry sand
BPZ: Concrete pozzolan containing pozzolanic aggregate and sand pozzolan

1. Introduction

Concrete is a mixture to which the nature of its constituents may have an impact on its thermal and mechanical characteristics. The formulation of a typical composition of a concrete requires the obtaining and the compliance with the desired properties such as the mechanical strength, durability, architectural appearance (shape, colors and textures), thermal and acoustic insulation.

Interest in building materials made from lightweight aggregate, notably, pozzolan concrete is due mainly to the development of the housing market and the need to reduce the cost of energy consumption ensuring, simultaneously, a thermal comfort in the habitat. Studies of the effect of the addition of pozzolan sand in composite materials of

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construction showed that this addition gives good thermal properties [1].

The weight is a very important factor. Its reduction leads to a reconsideration of the calculations of the supporting structures of the building construction, facilitates handling on construction sites; moreover, it enables considerable savings in terms of manpower and energy [2, 3].

Pozzolan which is of a volcanic origin, is located in considerable amounts in the quarry of Bou Hamidi in the region of Beni Saf in the west of Algeria [4]. It is ground in powdered form for use as a cement additive for the manufacture of cement, and in the form of granules for making lightweight concrete.

The direct impact on the housing construction industry is the lightness of the structure which can have an influence on the sizing calculation of the various elements constituting the building skeleton such as the columns, the beams and the foundations.

It is necessary for a material which is intended to the habitat to be characterized and identified for its thermo-physical and mechanical properties. The determination of the thermal conductivity and mechanical resistance to the simple compression of pozzolan concrete was successively conducted in the Laboratory of Mechanics and Materials at the Civil Engineering Department (LMM) and the Unit of Research of Materials and Renewable Energy (URMER) at the University of Tlemcen, Algeria.

2. Materials identification

2.1. Cement

The cement used for the different formulations belongs to the CPJ CEM II / A 42.5 which responds to the Algerian standard NA 442/2000 produced by the cement factory of Beni Saf in the wilaya of AinTemouchent. It consists of 80% of clinker and 15% of natural pozzolana. Its characteristics are shown in Tables 1 and 2.

Table 1

Chemical composition of cement%

SiO_2	25.63
Al_2O_3	3.66
Fe_2O_3	2.55
CaO	60.15
MgO	0.99
SO_3	2.53
CaO libre	1.02

Table 2

Physical characteristics of cement

Bulk density (kg/m^3)	1020
Absolute density (kg/m^3)	3071.2
Specific surface area (cm²/g)	3598.2

2.2. Sand

Two sands are used in the present investigation, the sand produced by the quarry of Sidi Abdelli which belongs to the National Company of Aggregates (ENG) of the Wilaya of Tlemcen and the pozzolan sand. Both sands have been the subject of a granulometric study. Figure 1 shows the particle size curves of the two sands. The characteristics of sands are shown in Table 3.

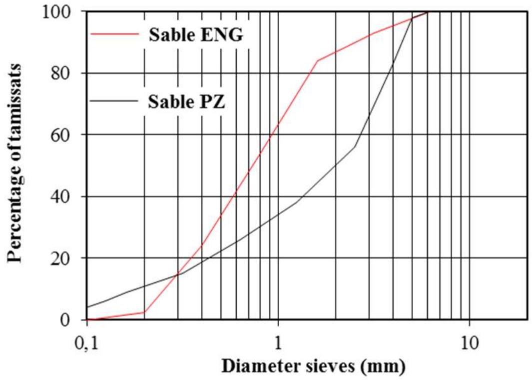

Fig.1 - Granulometric curve of sand

Table 3

Characteristics of the sand of the quarry of Sidi Abdelli and pozzolan sand

Characteristics	Sand of Sidi Abdelli S_{ENG}	Sand of pouzzolane S_{PZ}
Bulk density (kg/m^3)	1426	1155
Absolute density (kg/m^3)	2500	2450
Sand Equivalent (%)	63	
Fineness modulus	2.95	2.64
fines content (%)	17	21

2.3. Aggregates

The aggregates used in the study are from natural pozzolan of volcanic origin. The crushing and the granulometric study were conducted in the laboratory of the LMM. The particle size range selected is composed of two types of the gravel 3/8 and 8/16 with a maximum diameter of 16 mm.

The desired compressive strength of lightweight concrete requires a preliminary choice of the maximum diameter that will eventually decrease it. [5, 6].

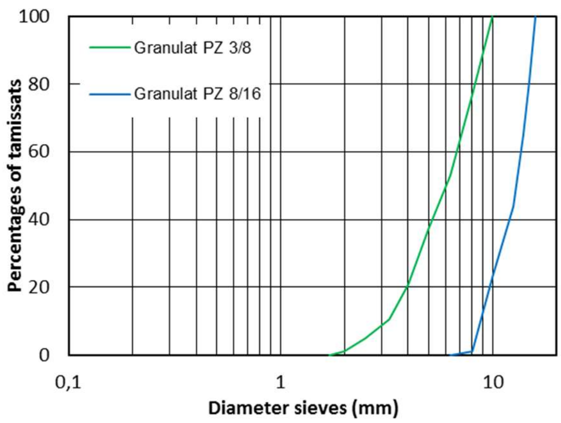

Fig.2 - Granulometric curve of the aggregates pozzolan

Table 4

Physical properties of pozzolan aggregates

Aggregate	3/8	8/16
Bulk density (kg/m^3	880	760
Absolute density (kg/m^3)	1870	1870
Porosity %	54.14	57.5
Absorption %	17.00	14.00

The granulometric study of pozzolan aggregates gave the grading curves of the two classes depicted in Figure 2. Table 4 shows the results of the physical and mechanical properties of pozzolan aggregates.

3. Concrete Composition

The composition of concrete is to achieve the optimum mixture of various proportions of aggregates (sand and gravel), the dosage of the cement, and the necessary amount of mixing water.

In formulating the concrete, the Dreux-Gorisse method was opted for because of the convenience and practicability it offers in the current study. It is used to investigate both the compressive strength and the workability desired from the essential database.

The weight ratio dosage on cement (absolute volume of cement) is set in advance according to the type of concrete to achieve. Three different dosages were opted for: 350, 300, and 250 kg / m^3. After several tests and corrections, the formulations designated in table 5 were determined.

As regards the compositions BGPZ1/3, BGPZ2/3 and BGPZ3/3, the volume of the sand of ENG quarry was reduced of 1/3 , determined from the method of Dreux and Goriss and increased up to 1/3 the volume of 3/8 pozzolan aggregates [7]

4. Mechanical characterization

The mechanical compressive strength of a concrete remains always the dominant quality to search for. Compressive strength tests are performed on cylindrical specimens (16cmx32cm) with conservation at ambient air (T = 20 ± 2 ° C and RH = 45 ± 10%) and shortly before their surfaces are covered with sulfur for the needs of the test.

4.1. Compression testing

The compressive resistance measurements were carried out on standard test specimens using the testing machine in compression according to standard NF P18406, 1981. The samples are loaded continuously at an average speed of 0.10 MPa /s. The maximum load F and the compressive strength are given directly by the machine.

The resistance was determined to simple compression at different hardening ages of pozzolan concrete, notably, at the 7th, 14th, 28th and 90th day.

5. Thermal characterization

The thermal conductivity λ is defined as the constant of proportionality between the temperature gradient and the heat flow it causes and which results in the equation (1).

$$\Phi = -\lambda\, S\, \frac{dT}{dx} \qquad (1)$$

5.1. Experimental device

The thermal conductivity is the characteristic that was measured with the experimental device; its principal diagram is shown in Figures 3 and 4. It is

Table 5

Composition of the pozzolan concrete

Designation of concrete	Dosage cement c (kg/m^3)	Sand ENG S_{ENG} (kg/m^3)	sand pozzolan S_{PZ} (kg/m^3)	Aggregate pozzolan 3/8 (kg/m^3)	Aggregate pozzolan 8/16 (kg/m^3)	Water w (l)	Ratio w/c	Ratio A/S
BGPZ1	350	665	-	235	559	212	0.60	1.19
BGPZ1/3		443		457	559	200	0.57	2.29
BGPZ2	300	708	-	247	546	200	0.67	1.12
BGPZ2/3		472	-	483	546	200	0.67	2.18
BGPZ3	250	762	-	253	532	160	0.64	1.03
BGPZ3/3		508	-	507	532	150	0.60	2.05
BPZ1	350	-	602	254	559	224	0.60	1.35
BPZ2	300	-	633	273	546	200	0.64	1.29
BPZ3	250	-	669	293	532	190	0.76	1.23

based on the principle of steady state methods such as the method of guarded hot plate, the metric flow method, the method of the boxes [8,9] and the work done by [10]. Figure 5 shows the box containing the experimental device and which will serve to avoid creating convection around the measurement device.

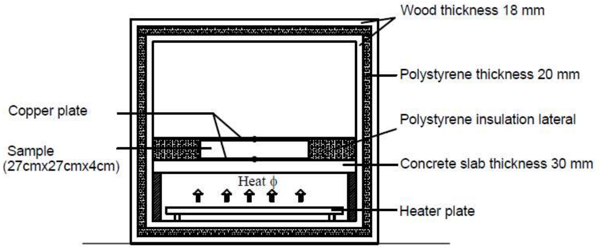

Fig.3 - Diagram of the principle of the measuring device of the thermal conductivity.

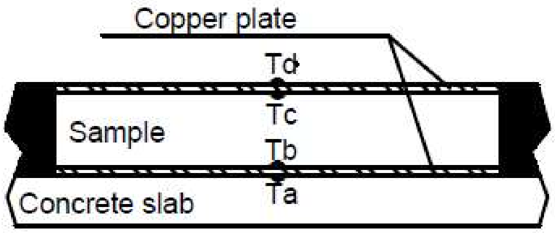

Fig.4 - Expanded view of the copper plates and sample mounting.

The temperatures Ta, Tb, Tc and Td are measured with the assistance of thermocouples located on either side of the two copper plates of Figure 4. The values of its temperature are detected by the multimeter M890C+.

Fig.5 - Experimental device

As with all stationary methods, the present device is based on the equation (1). The steady state is reached only if the incoming flow will be equal to outgoing flow. Thus, it suffices to measure the temperatures at four points a, b, c and d.

In steady state, the heat flow through the sample will be:

$$\Phi_{fd} = \lambda_{app} S \frac{(T_b - T_c)}{e_{sample}} \quad (2)$$

$$\Phi_{fd} = \lambda_{app} S \frac{(T_b - T_c)}{e_{sample}} \quad (2)$$

The flows in and out are determined successively by the formulas (3) and (4)

$$\Phi_{icf} = \lambda_{copper} S \frac{(T_a - T_b)}{e_{copper}} \quad (3)$$

$$\Phi_{ocf} = \lambda_{copper} . S \frac{(T_c - T_d)}{e_{copper}} \quad (4)$$

It can be stated that

$$\Phi_{fd} = \Phi_{icf} = \Phi_{ocf} \quad (5)$$

The value of the apparent thermal conductivity is calculated on the basis of the following formula:

$$\lambda_{app} = \lambda_{copper} \frac{(T_c - T_d)\, e_{sample}}{(T_b - T_c)\, e_{copper}} \quad (6)$$

5.2. Theoretical approach of experimental results

The pozzolan concrete is a porous material. To estimate its thermal conductivity, it has been assumed that the heat transfer by radiation and convection are insignificant in front of pure conduction [11]. To validate the measured values, it is considered that the pozzolan concrete consists of a solid phase (paste of cement + aggregate) and a fluid phase (air). The apparent thermal conductivity depends only on the conductivities of the two phases and the porosity rate of the material to be studied. Its calculation and prediction can be determined using models of diphasic porous media.

The apparent thermal conductivities were calculated using the models series, parallel, the mixed model and Hashin model represented by relations (7), (8), (9), (11) and (12).

The apparent thermal conductivity of the medium is written as follows:

The series and parallel model

$$\lambda_{serie} = \frac{1}{\frac{\varepsilon}{\lambda_f} + \frac{\alpha}{\lambda_s}} \quad (7)$$

$$\lambda_{parallel} = \alpha\lambda_s + \varepsilon\lambda_f \quad (8)$$

The mixed model (series-parallel)

$$\lambda_{app} = \frac{\lambda_{serie}\lambda_{parallel}}{\theta\lambda_{serie} + (1-\theta)\lambda_{parallele}} \quad (9)$$

With θ which represents the volume fraction of the disposed parallel part

$$\theta = \frac{\lambda_{parallel}(\lambda_m - \lambda_{serie})}{\lambda_m(\lambda_{parallel} - \lambda_{serie})} \quad (10)$$

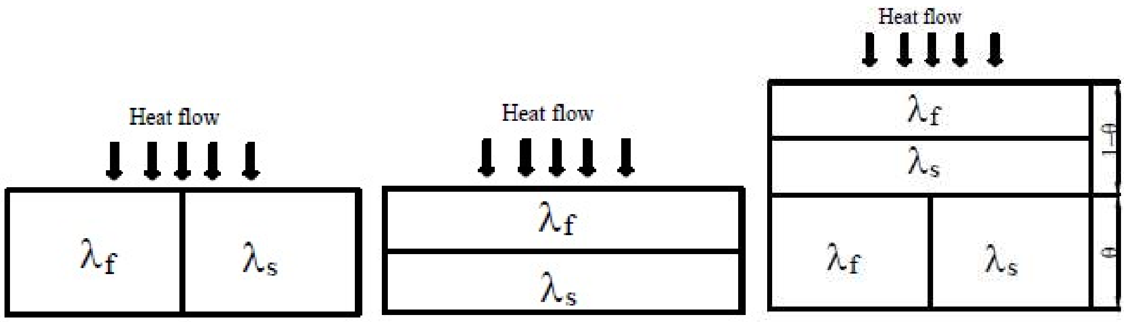

Fig. 6 - Diagram of the models series, parallel and mixed (serial-parallel)

And the model of Hashin with its min and max limits

$$\frac{\lambda_{app\,min}}{\lambda_f} = \frac{\lambda_s}{\lambda_f} + \frac{\varepsilon}{\frac{1}{1-\frac{\lambda_s}{\lambda_f}} + \frac{\alpha}{3\frac{\lambda_s}{\lambda_f}}} \quad (11)$$

$$\frac{\lambda_{app\,max}}{\lambda_f} = 1 + \frac{\alpha}{\frac{1}{\frac{\lambda_s}{\lambda_f}-1} + \frac{\varepsilon}{3\lambda_f}} \quad (12)$$

The porosity ε is a very determining parameter for physical properties at a macroscopic level. It can be calculated by the following formula cited by [12]:

$$\varepsilon = 1 - \frac{\rho_{app}}{\rho_{ag}} \quad (13)$$

With $\alpha + \varepsilon = 1$

6. Experimental results

The experimental results for the measurement of mechanical and thermal properties of pozzolan concrete are shown in the curves of Figures 7 to 19.

The Figures 7, 8 and 9 show the evolution of compressive strength at different hardening ages of the pozzolan concrete for three selected dosages (350, 300 and 250 kg / m^3). There is an increase of the compressive strength for all compositions of concrete. For a dosage of 350 kg/m^3 the concretes pozzolan BGPZ1, BGPZ1/3 and BPZ1 show higher strengths for all ages as compared to other compositions with dosages of 300 and 250 kg/m^3.

What can be observed in Figure 9 is that the compositions BGPZ3/3 and BPZ3 have the same resistance at 28 days; however, at 90 days the composition BPZ3 has a slightly higher resistance. The effect of pozzolanity plays an important role in increasing the resistance. The replacement of more resistant elements (sand quarry) through less resistance elements (sand pozzolan and lightweight aggregates), adversely affects the mechanical performance of the concrete [13]. Due to the high content of amorphous silica, there is a necessity for a more thorough investigation of possible harmful alkali-silica reactions in lightweight concretes properties [14].

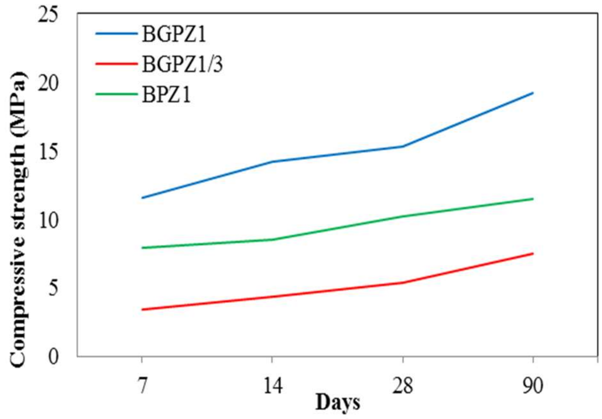

Fig.7 - The compressive strength of the concrete pozzolan for a cement dosage of 350 kg / m^3

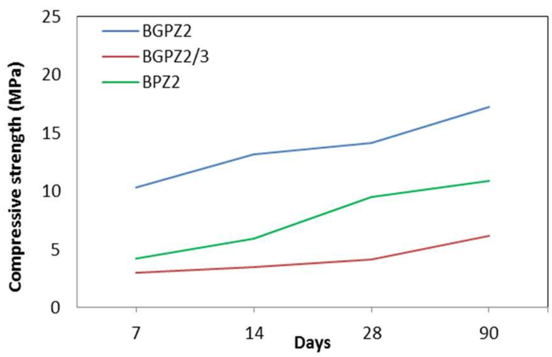

Fig.8: The compressive strength of the concrete pozzolan for a cement dosage of 300 kg / m^3

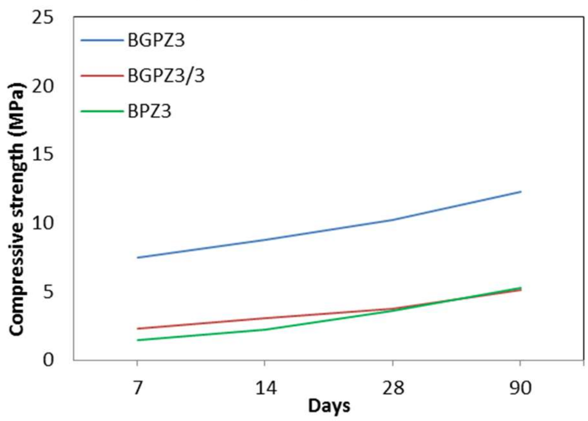

Fig.9: The compressive strength of the concrete pozzolan for a cement dosage of 250 kg / m^3

Figure 10 shows the effect of the use of Sidi Abdelli SENG quarry sand on the compressive strength for different ages of ripening. It has been noticed that the compositions BGPZ1/3, BGPZ2/3 and BGPZ3/3 present lower compressive strengths. This is related to the decrease in the volume of the quarry sand of 1/3 and the increase of the volume of the aggregate 3/8 by 1/3. It has been noticed, as well, that the concrete BPZ1, BPZ2 and BPZ3 which are composed of only pozzolan sand and two granular class 3/8 and 8/16, give relatively low resistance compared to BGPZ1 compositions and BGPZ2 and BGPZ3. Therefore, it is observed that the quarry sand increases the mechanical strength.

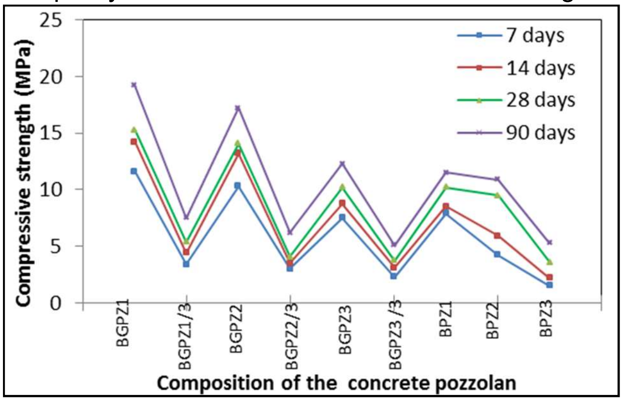

Fig.10 - Effect of Sidi Abdelli sand carrier S_{ENG} on the compressive stress for different ages.

Figure 11 shows the development of the compressive strength as for different compositions of concrete at the function of the porosity ε at the28th and 90th day of ripening. It has been noticed that the resistance to compression decreases when the porosity increases, the greatest value of the resistance performed for different ages corresponds to a A / S ratio of 1.19 as mentioned in Figure 12. The pozzolanic aggregates have an internal structure constituted by pores, the cell and pore size are other factors that influence the compression strength value [15].

Figure 12 shows the effect of G / S ratio on the compressive strength at different hardening ages. The resistance is maximum for an optimum value of A / S ratio equal to 1.19. This result corresponds to the BPGZ1 formulation for a dosage of 350 kg/m^3. Furthermore, in accordance to what is usually observed with the conventional concretes, it can be noticed in Figure 12 that increasing the A / S ratio causes a decrease in the compressive strength.

Finally, all pozzolan concrete compositions present a rather vertical cracking during the compression test when the critical threshold of stress is reached; this is mainly due to the aggregates which have a low adhesion [16].

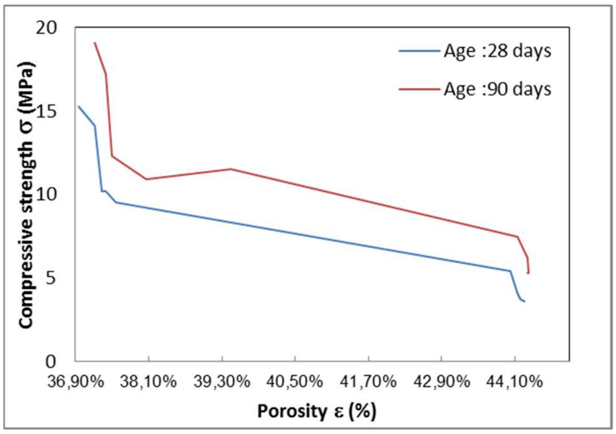

Fig.11 - Evolution of the compressive strength as a function of porosity for different pozzolan concretes (28th day and 90th day).

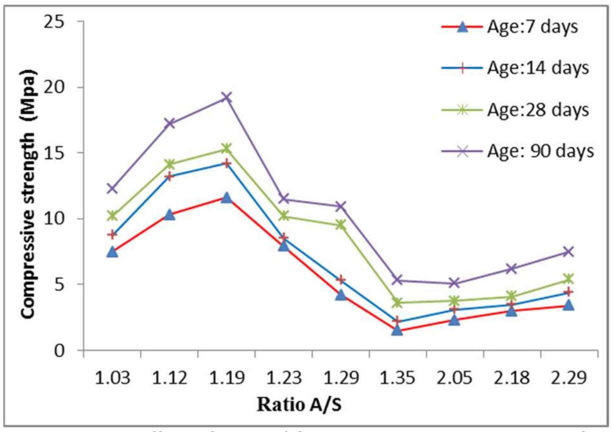

Fig.12 - Ratio effect of the A / S on the compressive stress of the pozzolan concrete for different ages.

For a thermal comparative study between the experimental and theoretical, the apparent thermal conductivities were calculated using the series, the parallel and the mixed models for typical values of conductivity of the solid phase. The figures 13 to 16 show the evolution of the apparent thermal conductivity λ measured and calculated by the series and parallel models, the mixed model in addition to Hashin and Shtrikman model for some typical values of conductivity of the solid phase. The results uncovered that the conductivity decreases as porosity increases.

Note that in Figures 15 and 16, the measured thermal conductivity and that of the mixed model are always between the thermal conductivities of series and parallel models. It has been found that for the value of the conductivity of the solid phase λs =1 w/mk (see Figure 13), the values of the measured thermal conductivity and that of the mixed model are practically located outside the limits of the models and parallel series. The results obtained from the mixed model and the measured values are in good agreement for all values of the conductivity of the solid phase. This result is a direct consequence of the experimental calibration that ensures that this model depends heavily on the quality of measurements.

In Figure 15, the theoretical values of the mixed model and Hashin model are in agreement with the experimental values. In addition, the results obtained are located between the extreme values of the series and the parallel models.

In Figure 16, the gap between the limitations of the series and parallel models is too important for predictive modelling of heat conduction. This means that the solid phase imposes the total conductivity. The model of Hashin which presents the most restrictive upper and lower limits does not give the desired result because these limit values were reversed for the value of the thermal conductivity of the solid phase λs =1.7 w/m k

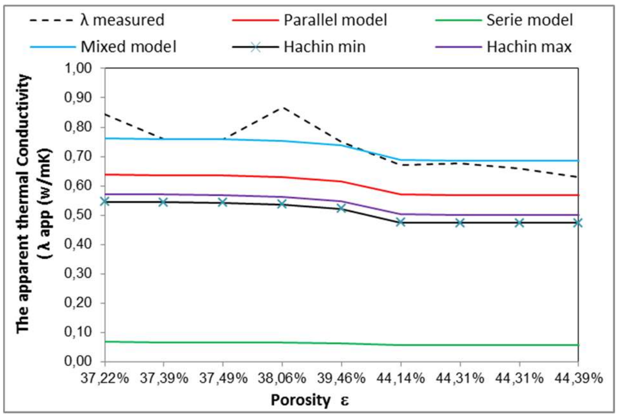

Fig.13 - The evolution of the apparent thermal conductivity λ measured and calculated by the series and the parallel models, the mixed model and the Hashin Shtrikman model in terms of the porosity of the concrete for (λs =1 w/mk).

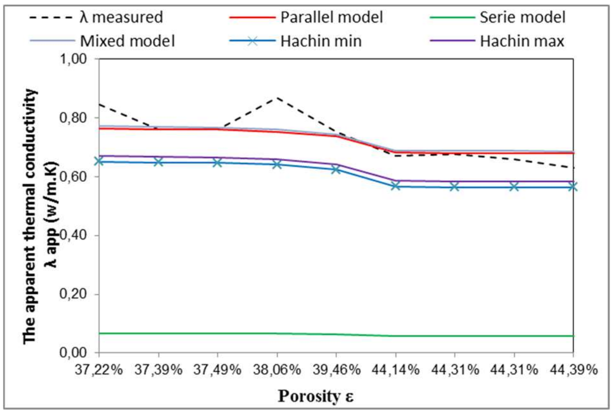

Fig.14 - The evolution of the apparent thermal conductivity λ measured and calculated by the model series, parallel, the mixed model and the one Hashin Shtrikman, depending to the porosity of the concrete for (λs= 1,2 W / m K).

Figure 15 presents the most logical results for a prediction of the apparent thermal conductivity and the deduction of the value of the conductivity of the solid phase.

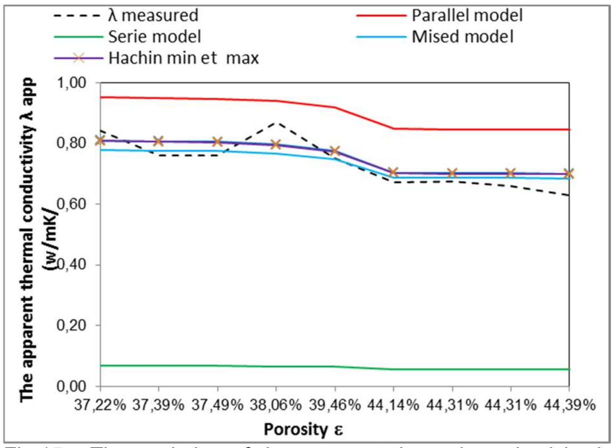

Fig.15 - The evolution of the apparent thermal conductivity λ measured and calculated by the model series, parallel, the mixed model and the one Hashin Shtrikman, depending to the porosity of the concrete for (λs= 1,5 W / m K).

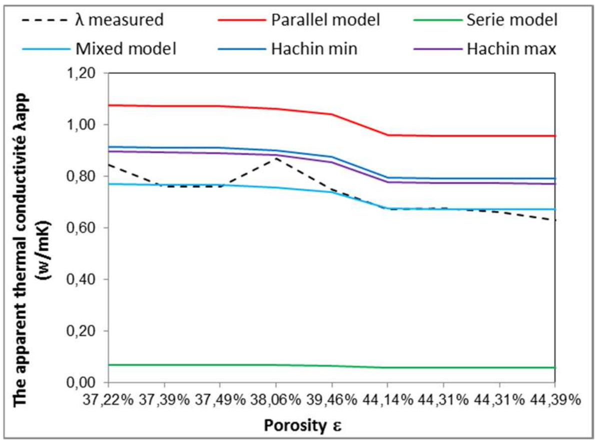

Fig.16- The evolution of the apparent thermal conductivity λ measured and calculated by the model series, parallel, the mixed model and the one Hashin Shtrikman, depending to the porosity of the concrete for (λs= 1,7 W / m K)

The thermal conductivity of a consolidated environment depends closely on the thermal conductivity of the solid phase. The measurement of the conductivity of the solid phase is a serious obstacle from the experimental side.

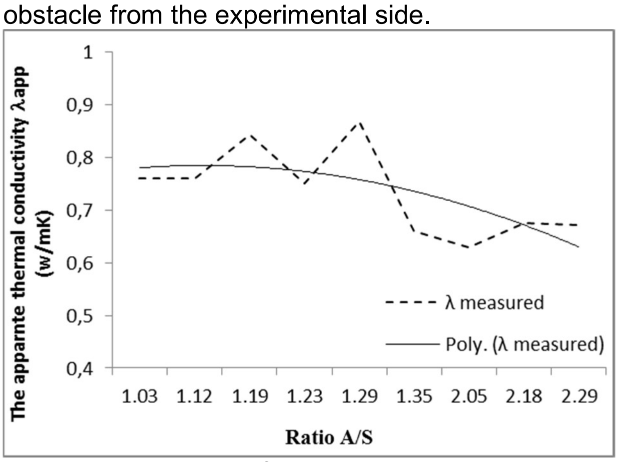

Fig.17 - The evolution of the measured apparent thermal conductivity in terms of the ratio Aggregate / Sand (A / S).

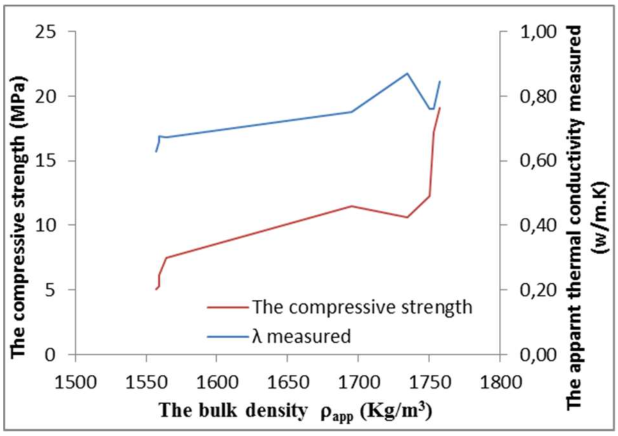

Fig.18 - The variation in the thermal conductivity and mechanical strength in terms of the bulk density of the concrete.

Figure 17 shows the evolution of thermal conductivity measured in terms of the ratio granulate / sand. It can be observed, then, that the thermal conductivity decreases with increasing the A / S ratio. The same observation was made by [17] when he showed that the as the volume of aggregates increases the density and the thermal conductivity decrease. According to Figure 12, the increase of the A / S ratio causes a decrease of the compressive strength. Therefore, the thermal conductivity and mechanical resistance both decrease in relation to the increase in the A / S ratio. In addition, figure 18 shows that the increase in the density leads to the increasing thermal conductivity and mechanical resistance [3]. It has also found out from the results that the density of lightweight aggregates is often the primary criterion to assess the quality and influence on the properties of lightweight aggregate concrete [18].

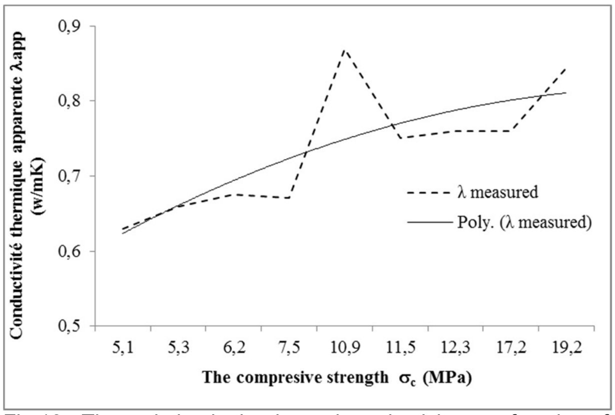

Fig.19 - The variation in the thermal conductivity as a function of the compressive strength of concrete.

The plot of figure 19 shows the evolution of the thermal conductivity measured as a function of the compressive strength. This curve shows the variation of thermal conductivity and the mechanical strength. It is easily observed that the thermal conductivity increases as the mechanical stress increases.

A criterion of choice of the field of lightening materials for which the concretes can be used as thermal insulation or as insulating bearer

7. Conclusion

The present investigation was designed to evaluate the mechanical and the thermal characteristics and the possible substitution of conventional granular materials used in the production of concrete by a material containing the lightweight natural ground pozzolan aggregate. It has thus been noted that the pozzolan concrete has a relatively low thermal conductivity compared to conventional concretes. One of the qualities sought is the lightness of this concrete besides the acceptable compressive strength. The mechanical results obtained show that the concrete complies with current standards [19].

After the testing of the mechanical resistance, an increase in the compressive strength for all compositions of the concretes has been observed according to ripening age and the cement dosage. The concretes which are composed only of sand pozzolan give fairly low resistances over the compositions with quarry sand.

The comparison of experimental results and the prediction of the apparent thermal conductivity by analytical calculations using theoretical models show that:

The measured values and the values of the models unveil the increase in the thermal conductivity when the porosity decreases.

The conductivity of the solid phase affects the apparent thermal conductivity; the higher the input value of the solid conductivity, the greater the gap between the parallel model and the series model, especially in relation to the results of figure 16.

With the model of Hashin having the most restrictive limits, the measured values of the thermal conductivity should be between both the upper and the lower bounds of the model. For λs =1w/mk and 1,2 w/mk, the values of the model of Hashin are below the values measured and are reversed for λs = 1.7 w/mk. The explanation for these results is the basic assumption of this model or the lower limit of the conductivity corresponding to the case where the inclusion possesses superior thermal properties to those of the matrix and conversely for the upper bound made by [20].

Figure 15 shows the most logical results for a prediction of the apparent thermal conductivity and deducting the value of the conductivity of the solid phase.

The measured values are within the range of the parallel and the series limits, the mixed model and the model of Hashin, their results are in agreement bearing in mind that the boundaries of Hashin model are confused.

This study was conducted for the purpose of the evaluation of pozzolan deposits of Beni Saf (Wilaya of Ain-Temouchent) in Algeria. According to the results obtained with different compositions of concrete, various possible uses can be considered. These concretes give remarkable thermal isolation for different chosen cement dosages.

The theoretical and experimental results obtained are encouraging and offer promising perspectives in the field of housing and the construction of work of art, underlining, as well, its thermal (thermal comfort) and acoustic interest.

REFERENCES

1. J.C. Damfeu, P. Meukam, and Y. Jannot, (2016) "Modeling and estimation of the thermal properties of clusters aggregates for construction materials: The case of clusters aggregates of lateritic soil, sand and pouzzolan." International Journal of Heat and Mass Transfer*, 2016,* **102,** 407.

2. P. Meukam, et al,"Caractérisation Thermophysique et Mécanique de Briques de Terre Stabilisées en Vue de l'IsolationThermique de Bâtiment." Materials and structures, 2003, **36**(7), 453.

3. S Gaye, F Niang, G Menguuy, G Sissoko, Thermal and Mechanical Characterization of Recycler Polymer Concrete, Journal des sciences, 2001, **1** (1)**,** 53.

4. Belaribi, N. Belas, M. Semcha, and L. Laoufi, "Influence de la Pouzzolane de Beni-Saf sur les Caractéristiques Mécaniques des Bétons." Canadian Journal of Civil Engineering, 2003, **30**(3), 580.

5. ACI 213 R-03, Guide for structural lightweight-aggregate concrete, Reported by American Concrete Institute, 2003, 213. USA

6. A.M. Neville, "Propriétés des Bétons» Editions Eyrolles.", 2000.

7. J. Leveau, and al, "Caractérisation Thermique de Bétons de Pouzzolane Utilisés dans le bâtiment." Journées internationales de thermique. 1987, 3. Lyon, France.

8. M. Filali, "Conductivité Thermique Apparente des Milieux GranulairesSsoumis à des Contraintes Mécaniques: Modélisation et Mesures." Ph.D. Dissertation, 2006, Institut National Polytechnique De Toulouse France.

9. Yves Jannot, "Séminaire de formation à la Métrologie Thermique." Laboratoire d'Energétique et de Mécanique Théorique et Appliquée (LEMTA), Laboratoire d'Energie Appliquée (LEA), Dakar, 2008, 12.

10. Laurent Libessart, Sébastien Gavory, Evaluation des conductivités thermiques matériaux consistants des murs végétalisés, rapport bâti et biodiversité positive, mesures thermiques et essai sur place, 2014, 1-58 HEI, Groupe ISA-ITIAPE France.

11. Robert Siegel, and John R. Howell, "Thermal Radiation Heat Transfer, McGraw 1972, Hill." New York.

12. J-P. Laurent,, "La Conductivité Thermique 'à Sec des Bétons Cellulaires Autoclavés: Un Modèle Conceptuel." Materials and Structures, 1991, **24**(3), 221.

13. L.H. Nguyen, Béton de Structure à Propriétés d'Isolation Thermique améliorées: Approche Expérimentale et Modélisation numérique. PhD Dissertation, 2013, Université de Cergy-Pontoise France

14. M Popov, L Zakrevskaya, V Vaganov, S Hempel and V Mechtcherine Performance of Lightweight Concrete based on Granulated Foamglass, 2nd International Conference on Innovative Materials, Structures and Technologies, IOP Conf. Series: Materials Science and Engineering, 2015, **96**, 1.

15. Hadi Ahmad, et al, "Different pore size alumina foams and study of their physical and mechanical properties." Mater. Sci. Eng, 2009, **13**(2), 340.

16. H.J.Chen, C.H. Huang, Z.Y. Kao, Experimental Investigation on Steel-Concrete Bond in Lightweight and Normal Weight Concrete. Structural Engineering and Mechanics, 2004, **17**(2), 141.

17. Sofia Real, and al, "Thermal Conductivity of Structural Lightweight Aggregate Concrete." Magazine of Concrete Research, 2016, 1.

18. L.H. Nguyen, et al, "Béton de Structure à Propriétés d'Isolation Thermique Améliorées: Approche Expérimentale.". XXIXe Rencontres Universitaires de Génie Civil. Tlemcen, 29 au 31 Mai 2011

19. AFNOR, Rrecueil de normes françaises, bâtiment et génie civil, granulats, 1992 -.France

20. Zvi Hashin, and Shmuel Shtrikman., A Variational Approach to the Theory of the Effective Magnetic Permeability of Multiphase Materials." Journal of applied Physics, 1962, **33**(10), (3),125.

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