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MECHANICAL AND CHEMICAL CHARACTERISATION OF POZZOLAN OF MIDDELE ATLAS IN MOROCCO

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ABSTRACT: This paper presents an experimental study in order to determine the mechanicals properties of the concrete and mortar with pozzolan material. Crushed pozzolan was used as lightweight aggregate and natural sand was used in all mixes to produce a lightweight aggregate concrete. These pozzolanic materials are abundant volcanic area but its use is very limited. The characterizations studies of this material can be useful to product lightweights aggregates concretes, thermal isolated material for energy efficiency in building, environment impact and Sustainable development issues. The properties of hardened and fresh concrete produced from the pozzolan including workability, density, compressive strength, flexural strengths resistance were tested. The chemical, mineralogical analysis, geophysical properties (appearance and shape, natural water content, porosity, density and water absorption) are studied. The properties of the concrete studied were also compared with those of the standard concrete. In order to obtain more knowledge on the mechanicals and chemicals properties of pozzolan concrete, six mixtures were tested: one specimen with Portland cement (control) and tree mixtures with, 25%, 40%, and 100% of pozzolan. Fresh concrete mixtures were tested for workability and density. While for the hardened concrete specimens, compressive strength and flexural strength were determined after 3, 7, 14 and 28 days. X-ray fluorescence, X-ray diffraction and the scanning electron microscope was used to determine the microstructure and to determine the chemical and mineralogical composition of the material. The results of this study show that the replacement of 30% river sand by sand of pozzolan, increase the strength of the mixtures.

Keywords: Natural pozzolan, Characterisation, Mechanical, Chemical, Lightweit concrete

1. INTRODUCTION

Pozzolan is a siliceous material that can be used as an inexpensive substitute for cement in mortar and concrete mixtures. Some forms of it occur naturally and others are manmade. Pozzolan participates in a cementitious reaction with calcium hydroxide (i.e., lime) and other alkalis. The use of pozzolan with lime in masonry construction dates back to prehistoric antiquity.

Pozzolans are effective at lowering the concrete and the mortar's heat of hydration, which improves its workability and durability. It also resists both sulphate and al-kali-silica reactions, which makes it beneficial to use in large concrete projects such as building, bridges and dams [1].

The sources of pozzolan are naturally occurring pozzolan deposits product of volcanic activity. Pozzolan also can be derived from fired and crushed clay, such as bricks [2].

Pozzolan is defined as materials which, though not cementitious in themselves, contain reactive element such as silica and alumina in a divided form, which are capable to combine with lime in the presence of water to form mix compounds possessing cementing properties.

The concrete and the mortar in the building area represents a very large proportion of the total load on the structure, and a large portion in the building envelope, there are clearly considerable advantages in reducing its weigh and reducing thermal conductivity. One of the ways to reduce these, is the use of lightweight aggregate concrete and mortar like pozzolan material to improve building energy efficiency.

A study of the thermal properties of the Habri pozzolan used in building had done [3] in order to relate the strength qualities of the structure to the corresponding thermal comfort and energy efficiency. The aim of the work reported in this paper is to determine the effect of addition the pozzolan on the mechanical properties of concrete and mortar.

In this paper, the potential use of a natural raw material in the production of blended cement was investigated. The chemicals, mechanicals and pozzolanic characteristics of the samples were examined to correlate the performance of the concrete and mortar produced.

Many authors [4–5] in their investigations reported that lightweight concrete has its obvious advantages of high strength/weight ratio, good tensile strength, low coefficient of thermal expansion, and superior heat and sound insulation characteristic due to air voids in lightweight aggregate.

Furthermore, the formwork supports less pressure with lighter concrete than the case with ordinary concrete, and also the total weight of materials to use is reduced with a consequent increase in productivity.

The reduction in the energy loss, the reduction in dead weight of a construction by the use of pozzolan could result in a decrease in energy consumption, CO2 emission and a decrease in cross sections of columns, beams, plates, and foundations with resultant reduction in construction costs.

In recent years, there has been a growing interest in the use of natural pozzolan as a mineral admixture to product concrete with good performance. A review of the studies on the use of pozzolan as a partial replacement for cement in mortar and concrete has recently been presented by several studies [6]–[7].

The effect of a natural pozzolan on the thermophysicals and mechanicals properties of concrete varies with the properties of the particular pozzolan and with the characteristics of the concrete mixture in which is used [3]-[8].

It is very important to know the function of the chemical interaction between the natural pozzolan and the Portland cement during hydration. Nevertheless, we still have limited knowledge of the way in which pozzolan influences the properties of concrete. Therefore, it is desirable to investigate the properties and behavior of each type pozzolan concrete and pozzolan mortar more comprehensively.

2. MATERIALS

The concrete mixtures and mortar were prepared at the laboratory of the Civil Engineering Department, EMI; Ecole Mohammadia d'Ingénieurs Rabat Morocco using the following materials:

2.1 Cement

The cement used was a blended Portland cement, obtained from Lafarge factory located in Rabat countryside, with following properties:

Having compressive strength 45MPa at 28-day and a specific density of 3150 kg/m^3. Initial and final setting times of the cement were 2 h 50 min, and 3 h 50 min, respectively. Its Blaine specific area was 3140 cm^2 /g.

2.2 Pozzolan

Fig.1 Natural deposits in Habri Middle Atlass mountain of Morocco

Pozzolan was obtained from natural deposits in Habri Middle Atlass mountain of Morocco (Source situated at about 20 km from Ifrane). This substance exists on the surface ground. Its chemical properties are given in Table 1.

This natural pozzolan was submitted many geotechnical tests so that we could identify it and compare their characteristics to others pozzolans. The tests made are:

Granulometry analysis, Proctor test, Slum test, specific density, Porosity, Absorption factor.

3. GEOTECHNICAL TEST

The particle-size distribution (PSD) of the used pozzolan presented in figure1 is a list of values or a mathematical function that defines the relative amount, typically by mass, of particles present according to size without grinding.

This analysis allows to determine the repartition of the grains dimension of the pozzolan, it allows us also to determine its classification.

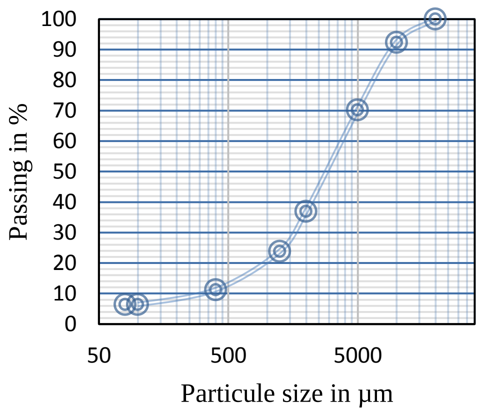

Fig.2 The granulometric curve of a sample of the pozzolan used

3.1 Proctor test:

The Proctor compaction test is used to determine the pozzolan compaction properties, specifically, to determine the optimal water content at which soil can reach its maximum dry density.

The optimal content of water is 21.66 % and its bulk density is 1430 kg/m3 for the pozzolan used.

Table 1 Physical properties of Habri pozzolan

Class test	0/5	5/16
Dry Density of the pozzolan stone (kg/m^3)	**1845**	
Bulk density (Kg/m^3)	1150	950
Specific density (kg/m^3)	2360	2260
Porosity (%)	51,27	57,96
Absorption factor (%)	14,14	10,98

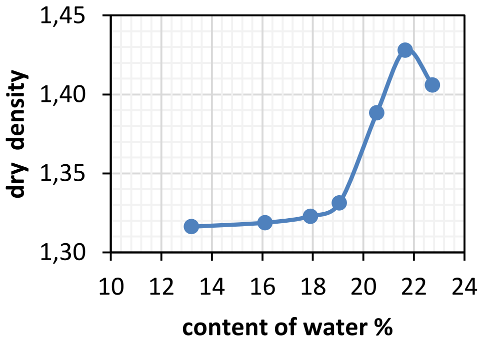

Fig.3 Dry density variation of the Habri pozzolan

3.1.1 Comparison of results

We compare the physical proprieties of the pozzolan that we have studied with others results of the literature.

Table 2 Physicals proprieties of different pozzolans

Aggregates	Origin	Class	Ref
LVS20/30	Djoungo, Cameron	20/30	[8]
LVS10/20		10/20	
LVS5/10		5/10	
LWCA1	Béni Saf, Algérie	2/8	[7]
LWCA2		8/16	
CVPA	Papua, New Guiné	1.18/20	[9]
FVPA		0.15/9.5	
DB1	Djoungo, Cameron	5/10	[8]
FB1	Djimbouot, Mfesset, Fosset	5/10	
FB2			
FB3			
FB4	(Foumbot), Cameron		[10]
G3/8	Béni Saf, Algérie	3/8	[7]
G8/15		8/15	
Scoria	Iceland	0/100	Euro LightCon
PZ0/5	Timahdite, Azrou, Morocco	0/5	
PZ5/10		5/10	

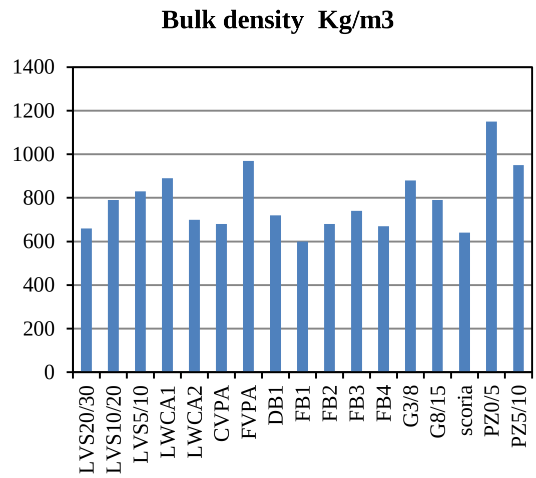

Fig. 4 Comparison of Bulk density of different pozzolans

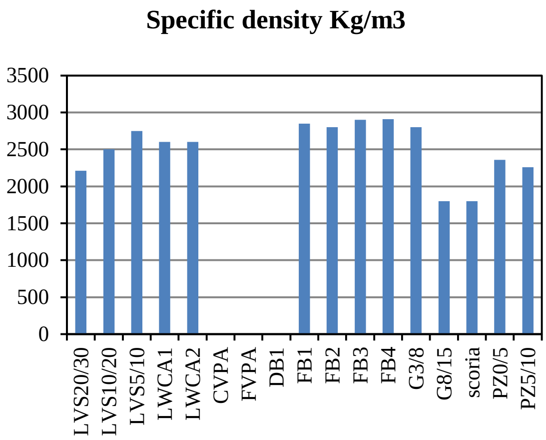

Fig. 5 Comparison of specific density of many pozzolans

The bulk density and specific density are shown in figure 4 and Figure 5. It was found that the bulk density ranging around 600-1000 kg/m^3 and specific density around 1800-2900 kg/m^3. The middle value of bulk densities is 749 kg/m3. Bulk density of Habri pozzolan for different classes is: PZ0/5= 1700 kg/m^3, PZ5/10=900 kg/m^3, the specifics densities are: PZ0/5=2400 kg/m^3, PZ5/10=2400 kg/m^3.

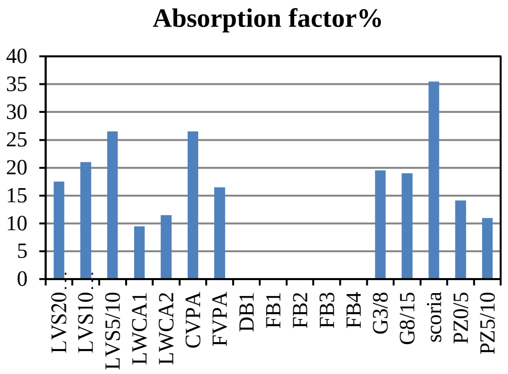

Fig. 6 Comparison of absorptions factors of different pozzolans

The absorption factor is a lower value in comparison to others pozzolans except the pozzolan of Béni Saf, Alger which has a near value.

3.3 Porosity:

Porosity of Habri pozzolan has compared with others in figure 7. The pore volume is calculated by subtracting the particle density from specific density.

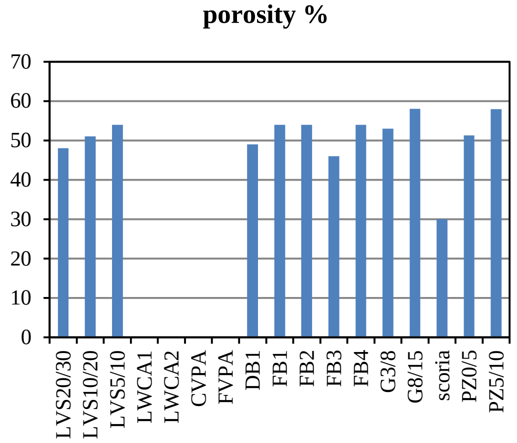

Fig.7 Comparison of porosity of different pozzolans

The figure 7 show that the habri pozzolan has the largest pore volume; 60% that can have a great influence on the thermophysics properties; thermal conductivity, diffusivity and effusivity, thus it can be interesting as a thermal isolated material

4. CHEMICAL PROPERTIES AND STRUCTURE ANALYSIS

4.1 Spectrometry Fluorescence X

The X-ray fluorescence technique was used in order to identify the chemical composition of three samples; the pozzolan stone, pozzolan-(5/10) and pozzolan powder. The obtained results are presented in Table 3. It can be noticed that the quartz (SiO_2), iron oxide (Fe_2O_3), alumina (Al_2O_3), CaO, and MgO are mainly presents in the samples, is in good agreement with literature and studies of pozzolan [11]. This is a promising result as both silica and calcium are important components in the cementitious reaction.

It can be seen that the silicon, aluminium, and iron contents are about 37, 14, and 17 percent respectively for every type of sample; pozzolan stone, pozzolan gravel and the pozzolan mix.

Table 3 Chemical composition of pozzolan by X-Ray fluorescence

	Pozzolan stone	Gravel	powder	Mix
SiO_2	37,47	37,47	37,33	35,13
Al_2O_3	11,4	14,33	17,67	13,90
Fe_2O_3	17,7	19,23	17,37	15,37
CaO	10,73	10,30	6,65	8,27
MgO	9,76	6,35	5,23	6,76
K_2O	1,40	0,44	0,22	0,25
Na_2O	5,12	1,23	0,62	0,87
TiO_2	2,99	3,57	3,50	3,03
SO_3	0,17	0,15	0,10	0,10
P_2O_5	1,127	1,19	0,88	1,05
PF	0,41	4,29	9,26	4,76

Table 4 Atomic composition of pozzolan by X-Ray fluorescence

	Pozzolan stone	Gravel	powder	Mix
O	41,67	43,93	47,57	40,73
Si	17,50	17,53	17,13	16,43
Fe	12,40	13,47	12,17	10,77
Ca	7,66	7,35	3,76	5,91
Al	6,05	7,60	10,02	7,36
Mg	5,89	3,83	2,45	4,08
Na	3,80	0,91	0,32	0,65
Ti	1,79	2,14	2,10	1,81
K	1,16	0,36	0,16	0,21
Cl	0,55	0,23	0,09	0,15
P	0,49	0,52	0,32	0,46
Sr	0,23	0,28	0,16	0,16
Mn	0,20	0,20	0,26	0,17
C	0,11	1,17	3,18	1,30
Ba	0,13	0,12	0,11	0,08
Zr	0,08	0,08	0,06	0,06
S	0,07	0,06	0,04	0,04
Ni	0,05	0,06	0,04	0,05
Nb	0,04	0,04	0,01	0,02

Zn	0,03	0,02	0,03	0,02
Y	0,02	0,02	0,02	0,02
Rb	0,02	0,02	0,01	0,01
Cu	0,00	0,01	0,00	0,00
Cr	0,04	0,06	0,02	0,06
I	0,03	0,04	0,03	0,03
Ac	0,01	0,00	0,00	0,00
CO	0,00	0,00	0,01	0,00

As we can observe in table 3 and table 4, the chemical composition of the 4 samples; pozzolan stone, pozzolan gravel, pozzolan powder and Mix is the same, so there is no contamination or geological alteration for different samples.

4.2 Comparison chemical composition between different pozzolans

Table 5 Comparison of chemicals analysis of different pozzolans

	Habri pozzolan Morocco	deposit of Saint Pierre (réunion)	Bouhamidi Algerie	Djongo Cameroun
SiO_2	37,47	38,35	42.05	45.79
Al_2O_3	14,33	16,65	16.32	15.66
Fe_2O_3	19,23	8,72	9.49	12.83
CaO	10,30	4,64	12.39	9.60
MgO	6,35	1,68	4.20	6.26
K_2O	0,44	3,10	1.39	1.39
Na_2O	1,23	5,12	3.00	3.54
TiO_2	3,57	5,12		2.84
SO_3	0,15		0.01	
$CaCO_3$			10.75	
MnO				0.17
P_2O_5	1,19			0.60
PF	4,29			0.31

4.3 X ray diffraction on powder:

X-ray diffraction (XRD) relies on the dual wave/particle nature of X-rays to obtain information about the structure of crystalline materials. A primary use of the technique is the identification and characterization of compounds based on their diffraction pattern.

The XRD pattern shown in figure 8 indicate the presence of mainly silica, iron oxide and alumina.

(Quartz: 2-theta = 20.9, 26.7, 39.5, 50.2, 60.0; Calcite and Magnesia: 2-theta = 29.4, 47.6).

The chemical compositions of samples analyzed using an X-ray Fluorescence spectrometer determines the oxide compounds such as calcium oxide (CaO), silica (SiO2), alumina (Al2O3), magnesium oxide and iron oxide (Fe2O3). Furthermore, minor compounds like SO3, K2O and Na2O were also determined.

The silica, the alumina and the iron oxide are the three essentials elements in the composition of the pozzolan. They are responsible of the fixation of the lime [12-13].

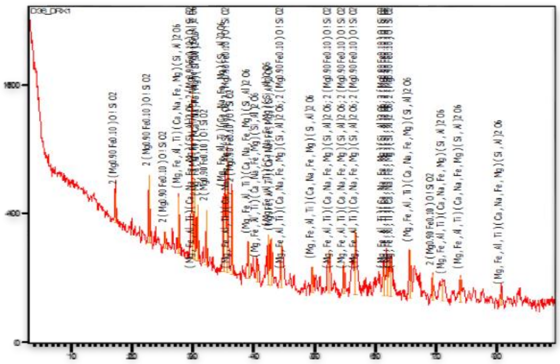

Fig.8 XRD Diffractogram

4.3 Scanning Electron Microscopy Tests of Pozzolan

Fig.9 Electronic scanning microscope

Pozzolan composition was investigated using scanning electron microscopy (SEM), which produces images by scanning a focused electron beam across the specimen surface. The x-ray produces a unique signature for each different element, so the x-ray energies emitted provide information that identify chemical composition

The morphology and microstructure of Habri pozzolan are obtained by using scanning electron microscopy (SEM), the SEM micrographs shown in figure 10 displayed the presence of pores having various dimensions that can be an important material for isolation thermal in building issues.

The image obtained by the ESM is analyzed by EDS. With this analysis we determine the percentage of every chemical element, the result is presented in table 6:

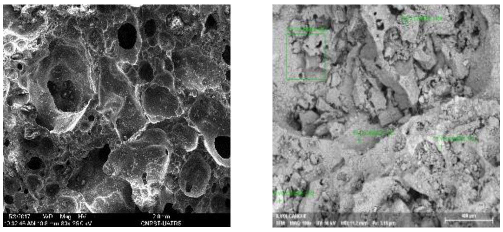

Fig.10 MEB Images

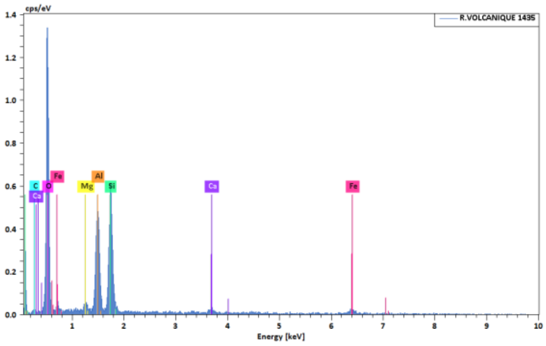

Fig. 11 Diffractogram of Habri pozzolan

Table 6 chemical element of used pozzolan

Element	O	Si	Ca	Al	Mg	Ti
Percentage	48,99	19,66	4,90	8,23	1,78	1,46

The oxygen (O) and the silica (Si) are the most existing atoms by an average percentage of 43% and 17% respectively which makes the molecule SiO_2 the most existing in the samples.

4.5 Comparison of results fluorescence and SEM analysis:

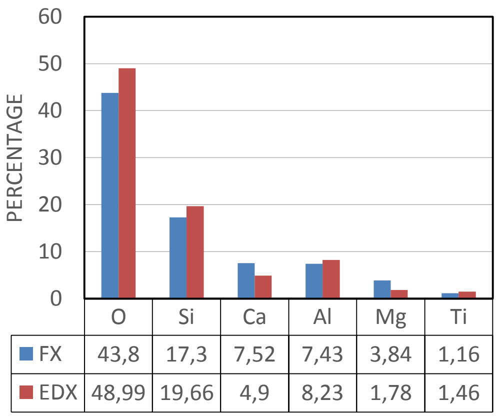

Fig. 12 Comparison of results fluorescence and SEM analysis

As we can observe, the chemical analysis for to methods XF and SEM are nearly equal.

5. MECHANICAL TESTS

5.1 Preparation and casting of test specimens:

Six mixtures were made to compare the effect of adding pozzolan gravel and pozzolan sand replacement material. First was a reference specimen concrete BT (without pozzolan), and the five others concretes mixtures were made by replacing gravel with 10%, 20%, 30%, 40%, and 50% of pozzolan gravel; respectively, BGP10, BGP20, BGP30, BGP40, BGP50, second was a reference specimen mortar (without pozzolan), and five others mortars mixtures made by replacing sand with 10%, 20%, 30%, 40%, and 50% of pozzolan sand respectively, BSP10, BSP25, BSP30, BSP40.

Table 7 Classes of consistence

Type Concrete	CONSISTENCE
BT	Gravel (100% gravel stone) Sand (100% sandstone)
BGP25	Gravel (25% Pozzolan) Sand (100% Sandstone)
BGP40	Gravel (40% Pozzolan) Sand (100% Sandstone)
BGP100	Gravel (100% Pozzolan) Sand (100% Sandstone)
BSP25	Gravel (100% Gravel stone) Sand (25% Sand pozzolan)
BSP40	Gravel (100% Gravel stone) Sand (40% Sand Pozzolan)

Table 8 Physicals proprieties of different samples

	Mass of the test sample (Kg)	Volume of the test sample (m^3)	Density (KN/m^3)
BT	14,88	0,006	23,11
BGP25	14,5		22,53
BGP40	14,25		22,14
BSP25	14,85		23,08
BSP40	14,8		23
BGP100	13,2		20,51

5.2 Slump test

Table 9 Average slumps and classes [15]

Slump Class	Slump range (cm)	Workability
S1	1≤A≤4	Closed
S2	5≤A≤9	Plastic
S3	10≤A≤15	Very plastic
S4	16≤A≤21	Fluent
S5	22≤A	Very fluent

The slump test [13] and compacting factor test [14] were used in assessing the workability of the fresh concrete mixes with pozzolan material.

The workability of the mixture was ensured through Abrams cone and flow table tests for concrete with pozzolan and mortar with pozzolan, respectively. The slump of the fresh concrete prepared was measured using the standard slump test apparatus [15].

Figure 13 shows slump test results. From a rheological point of view, the use of the addition in fresh state improved the cohesion. As we can see from figure 13, the mixtures lost consistence after the incorporation of pozzolan. This can be the result of the fact that pozzolan has an important porosity structure that retains water.

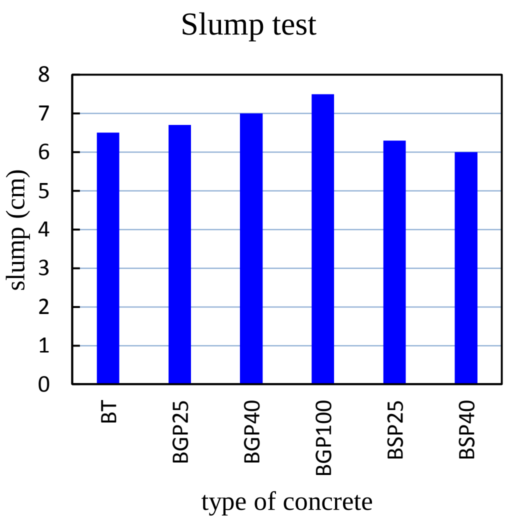

Fig. 13 Slump test with differents amount of pozzolan

5.3 Compressive strength

The principle of the test is to apply an increasing and constant force to a cylindrical specimen until it breaks in order to determine its compressive strength. The test pieces are made in the Materials Laboratory of the civil engineering department of the Mohammadia school of engineers, in cylindrical molds of dimensions: height h = 32 cm and diameter d = 16 cm. The specimens were allowed to cure in the open air before determining their compressive strength at 7, 14, 21 days and 28 days. For each composition of the pozzolanic concrete, 3 test samples are made in order to be able to averaging 3 values obtained and discard the non-significant values.

The values obtained for pozzolanic concrete are compared with reference concrete (without pozzolan) to see the influence of the substitution effect of either gravel or sand by pozzolanic gravel and pozzolanic sand with well-defined proportions.

The compressive strengths data for 3, 7, 14, 21 and 28, days age of the concrete made either with and without pozzolan are plotted in figure 14 and table 10, It is seen that the strength of concrete increases with age. As expected, the early strength gain of the control mixtures without pozzolan was superior to that of the pozzolan mixtures, a decrease in compressive strength was observed as the percentage of gravel pozzolan replacement increased. For example, at 7 days, the compressive strength with 25% and 100% of pozzolan replacement levels were 16.1MPa and 10.6MPa, respectively. At 7, 14, 21 and 28 days the 40% pozzolan sand replacement is a higher

The highest compressive strength was noted in the 40% sand pozzolanic replacement concrete (22.85MPa) in 28 days age followed by those prepared with 25% sand pozzolanic (22.4MPa), the control concrete (22MPa), 25% gravel pozzolanic replacement (18.30MPa), 40% gravel pozzolanic (17MPa) and finally 100% gravel pozzolanic concrete. This result is in agreement with others authors [8] for cement replacement by pozzolan powder. As explained by M. Mouli and all [8]; replacement may be explained by that pozzolan transforms Ca(OH)2, which is the hydration product of the cement into C–S-H

The use of the addition of pozzolan sand improved the cohesion. This increases the contact among solid particles giving the mix more cohesion. The lowest compressive strength (11.50MPa) was noted in the concrete specimens prepared with 100% pozzolan replacement of gravel from 7 at 28 days.

Table 10 Compressive strength (MPa)

Age at testing (days)		7	14	21	28
Type of concrete and Pozzolan Replacement	BT	14,50	17,06	19,75	22,20
	BGP25	13,40	15,84	17,48	18,30
	BGP40	12,65	15,00	16,64	17,70
	BGP100	6,70	8,54	10,83	11,50
	BSP25	14,90	17,14	19,86	22,40
	BSP40	18,27	19,24	21,19	22,85

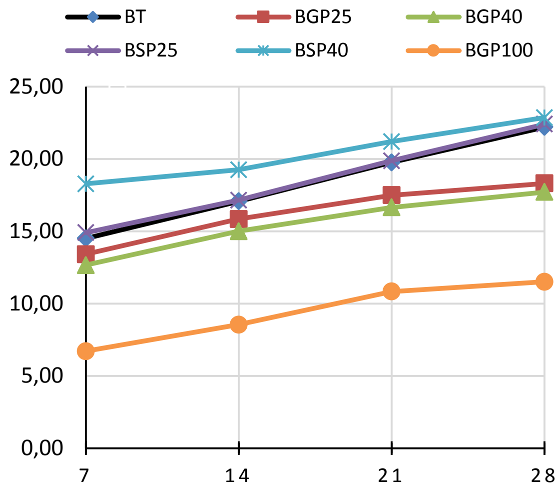

Fig. 14 Variation of compressive strength with age

The result of mechanical test carried out in order to assess the compressive strengths of de studied samples materials are between 15 and 25MP in 30 days age. For mix 1, 25MP, for mix 2, 20MP, for mix, 18MP, for mix 3, 18MP, for mix 4, 15MP. The relative small values of compressive strength with pozzolan, can be explained by the presence of pores in the material but it is an advantage to reduce the heat flux transfer for energy efficiency.

5.4 Flexural strength.

The variation of the flexural strength with the percentage replacement of pozzolan in the concrete is presented in the table 11 and figure 16. The result illustrates that at early ages the strengths are lower than later ages. Similar to the case of the compressive strength, the flexural strength of the pozzolan concretes depends by the percentage of pozzolan in the mixture content.

At 7 days ages the flexural strength for the pozzolan concrete ranged from 2.2 to 3.7MPa. At 28 days, the mixture containing 25% pozzolan developed higher flexural tensile strength than the standard control mixture.

Fig. 15 Flexural strength test

Table 11 Flexural strength (MPa)

Type Concrete / Age	7	14	21	28
BT	5,15	5,79	6,4	6,82
BGP25	3,79	3,82	4,1	4,22
BGP40	3,36	3,41	3,75	3,96
BGP100	2,22	2,24	2,31	2,34
BSP40	2,34	3,12	3,55	4,12
BSP25	3,5	4,22	4,85	5,12

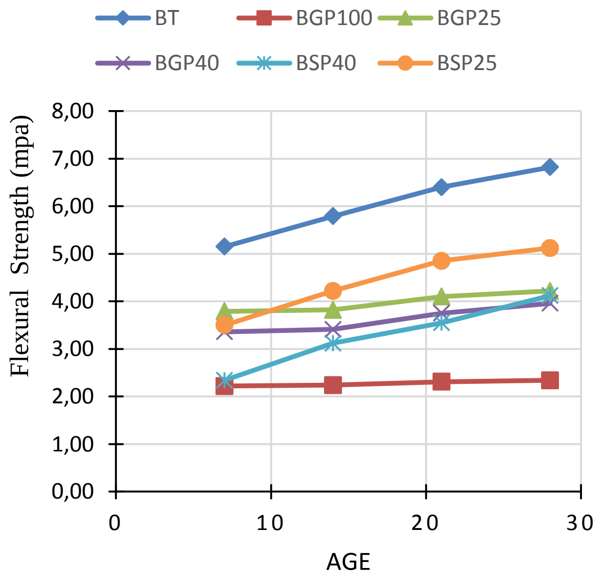

Fig 16 Flexural strength test with differents amount of pozzolan (MPa)

The principle of the test is to determine the flexural strength of the hardened concrete specimens according to procedures; 3 points bending tests. The specimens are made of parallelepiped mold of dimensions $14 \times 4 \times 4$ cm^3. The test is carried out with a bending machine of the mechanical workshop of the National Higher School of Mines of Rabat. The machine is computer-aided. It exerts an increasing force after defining the parameters of the test until the test piece breaks, for each composition of the pozzolanic concrete, 3 tests pieces are made in order to be able to average the values obtained by comparing them with those of a standard control concrete.

6. CONCLUSIONS

Based on the results of experimental work, Habri pozzalan material can be used in the production of lightweight concrete for structural and for thermal insulation purposes. The thermal resistance of light weight concrete can be improved by mixing with light weight aggregates such as pozzolan, it will reduce the coast of energy consumption and environmental pollution. Knowledge about physical, chemical and mechanical properties can be help to control castings, mechanical properties and durability for lightweight aggregate concrete production. Replacement with pozzolana sand significantly increased the strength of concrete. The thermos-physics properties study are necessary for to use this material in the building sector for the energy efficiency.

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