Experimental Study on the Formulation of Pozzolanic Concretes According to the Physico-Chemical Parameters

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Article Info

Article history:

Received November 23, 2022
Revised December 08, 2022
Accepted December 13, 2022

Keywords:

Natural pozzolana
Durability
Mechanicalresistance,
Pozzolanic concrete
Formulation
Mineraladdition.

ABSTRACT

These Cement additives are now recognized and accepted as desirable, even essential constituents of concrete for technical, economic and ecological reasons. During cement production, a significant amount of CO_2 is released into the atmosphere. Global clinker production is responsible for approximately 7% of total CO_2 emissions.The use of additives such as slag, fly ash, natural pozzolan as a constituent of cement can cause a reduction in the quantity of clinker required per tonne, hence reduced CO_2 emissions. These additions not only offer technical advantages to the new material, but also constitute an important contribution for the cement industry. The purpose of this work is the study of the physico-mechanical properties of cement-based concretes, part of which is reinforced by the pozzolan of Beni-Saf, which is very available in the Oust of Algeria and which seems to be it has excellent powder qualities; through a comparative study between some formulations of pozzolanic concretes which have been made by different researchers, and the influence of these formulations on the physico-mechanical parameters of concretes in order to obtain the best formulation and apply it experimentally. Slump, apparent density, compressive strength and tensile strength by bending and their evolution over time are the various tests carried out to study the durability of concretes made with pozzolan. The results found demonstrated that natural pozzolan improves the strength of concrete over time.

I. Introduction

Originally, the additions were launched for economic reasons. Either they exist in the form of natural products, or they result from industrial processes in the form of waste or by-products. In addition, there has been an increase in energy costs. Independently of these ecological and economic advantages, appropriate additions positively influencing certain concretes with particular properties (concrete with low heats of hydration, tinted concrete, concrete with compensated shrinkage, etc.) could not be manufactured. In addition, rainwater and underground water can penetrate the porous and capillary network of the concrete and bring with it aggressive ions which can react with hydrates (portlandite and CSH) and change their structure, so to reduce the porosity of concrete we use cementitious additions which have a very fine grain size that are most often incorporated into cement to improve the characteristics of concrete, in order to clarify all this we present the following reactions:
a-Hydration reaction of Portland cement (rapid reaction, lime production):

Influence of Limestone on the Hydration of Portland Cement

The Hydration of Portland Cement

$$C3S + H \longrightarrow CSH + CH \quad (1)$$
$$C2S + H \longrightarrow CSH + CH \quad (2)$$

Or :
CSH: hydrated calcium silicates
CH: Portlandite $Ca(OH)_2$
In addition, the Pozzolanic reaction (slow reaction, lime consumption):
Pozzolana + CH + HCSHCSH (3)

Additions are often cheaper than Portland cement and make it possible to obtain a more economical compound cement using these additions which are very inexpensive and available in large quantities in Algeria, such as El-Hadjar slag, limestone, and natural pozzolan. It is generally accepted that pozzolans have beneficial properties such as low heat of hydration, low permeability, high compressive strength.

As part of a research program and with the aim of enhancing these materials, we compare some results of the work of different researchers [1-7] that they allowed us to give some interpretation of the effect of natural pozzolan on the physico-mechanical properties of concrete.

Boubakir's study [1] on the development of high-performance concrete shows that the incorporation of active additions is necessary to improve the compressive and tensile strength of concrete to achieve a BHP. He also examined the following characteristics: workability, occluded area and shrinkage.

The conclusion drawn is that the addition of 10% of pozzolana has a better resistance and the use of the latter is important to obtain a high-strength concrete, however this resistance is always difficult to achieve and it exceeds 70MPa. Also proposed to substitute pozzolan with adjuvants to improve resistance.

An experimental program led by laoufi [2], aimed to study the influence of using pozzolana as a substitution for a part of cement in order to carry out tests to highlight the influence of pozzolana on the physico-mechanical properties of concrete, to study all this, laoufi [2], carried out a series of chemical, physical and mechanical tests. The tests were carried out on concrete containing different percentages of pozzolana (0%, 20%, 25% and 30%). The proposed solution showed that the optimum rate of pozzolan is that of 20% and for concrete with pozzolanic cement base, the compressive strengths approaching the Rc28 strength of the control concrete, but at a different age (long term, beyond 90 days).

The influence of cementitious additions on the behavior of concretes has been researched by Asroune [4] who showed a clear increase in the compressive strength of concrete with additions compared to concrete without additions and this is explained by the fact that the density concrete with additions is higher compared to concrete without additions, the fine grains of the additions fill a maximum of void between the grains of cement and the aggregates this is the case of high performance concretes.

Another study that estimates the influence of pozzolan on the physico-mechanical behavior of high-strength concrete was proposed by Drici [5] The proposed model was based on the substitution of natural pozzolan for cement is 10%, 20%, and 30% and the introduction of 2% adjuvant. Setting time, slump and compressive strength were studied.

In the same context, the researcher Gharnouti [3] demonstrated the physical behavior and experiments in concrete prepared by ultrafine cementitious additions, particularly silica fume, which has the same pozolanic properties and often named by artificial pozzolan, the use of mineral additions in the manufacture of high-strength concretes is a preferable alternative, because these substances make it possible, on the one hand, to greatly reduce the initial porosity of the cement paste of the concrete; which is a fillingeffect and on the other hand, they have a pozzolanic effect which is due to their reaction with Ca(OH)2.

For another purpose and to have more information on the effectiveness of pozzolan as an addition to concretes, the same author Mouli.M [7] conducted tests on six concretes: 0%, 10%, 20%, 30%, 40% and 50% pozzolan as a substitute for cement are tested. The compressive strength was researched where he [7-9] found that the addition of 10% pozzolan improves compressive strength beyond 28 days.

In this part we focus our attention on a confrontation between the different pozzolanic concrete formulations of the various researchers mentioned above, in order to choose the best formulation and apply it experimentally.

the results of the physical tests and mechanical tests for the various compositions studied show acceptable results and that which is, of the consistency and the apparent densities of the hardened concretes, as well as the percentage of the occluded area, all these results are presented and grouped in the following graphs as a graphical translation[10-12];

In order to better understand tables and graphs, here are the following designations;

Formulation N°1: The influence of cement additives on the behavior of concretes. [4]
Formulation N°. 2: The use of mineral additions in the manufacture of high-strength concretes. [5]
Formulation N°3: Effects of ultrafine cementitious additions on the durability and physico-mechanical properties of concretes. [3]
Formulation N°4: Formulation of a lightweight concrete based on pozzolan. [6]
Formulation N°5: Study of an ordinary concrete based on pozzolan as a substitute for cement. [7]
Formulation N°. 6: The physico-mechanical characteristics of concretes based on pozzolanic cement. [2]
Formulation N°. 7: Development and study of a high-performance concrete. [1]

- **Interpretation and analysis of the studied formulations**

According to the interpretation and the analysis of the formulations studied, we gathered the properties physical for each and which will be presented in the following table;

Table 1. The results of the physical tests of the various concretes.

Formulations	Pozzolana (%)	Sag(cm)	Density (%) (Kg/m^3)
Formulation N°1	10	7,9	2235
Formulation N°2	20	15	2285
Formulation N°3	5	9	2440
Formulation N°4	20	5.3	1800
Formulation N°5	10	7	2330
Formulation N°6	20	7	2345
Formulation N°7	10	8.7	2490

Based on this interpretation we can conclude that

The slump of the concrete increases proportionally with the percentages of addition and admixture as well as with their quality.
- Concerning the density of the concretes with additions, it is relatively high compared to the reference concrete. Natural pozzolan slightly increases the density of concrete. It gives rise to a second C.S.H which improves the filling of the pores and therefore increases its density.
Concerning the mechanical properties, will be gathered in the following graph:
Compressive strength Rc
Bending strength Rf

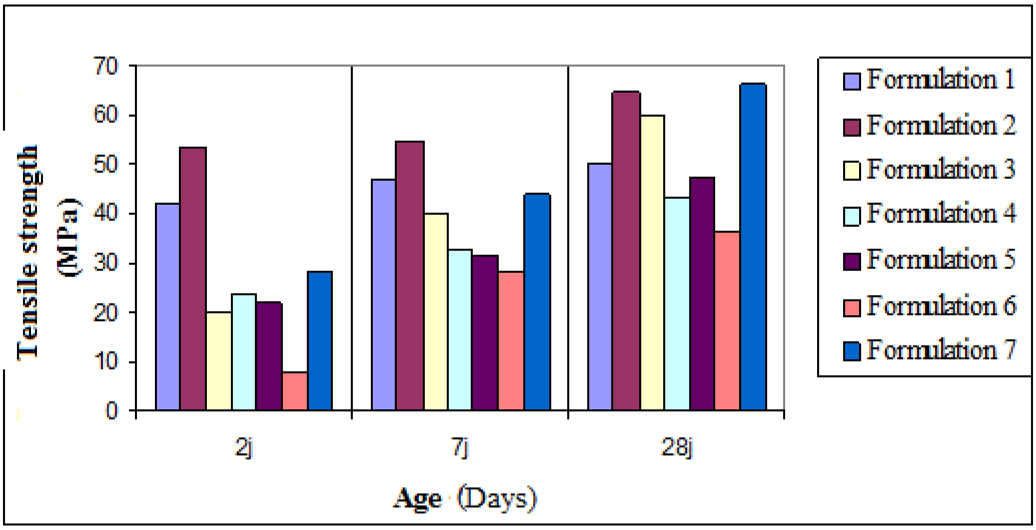

Figure 1. The influence of different formulations of concrete on its compressive strength as a function of age.

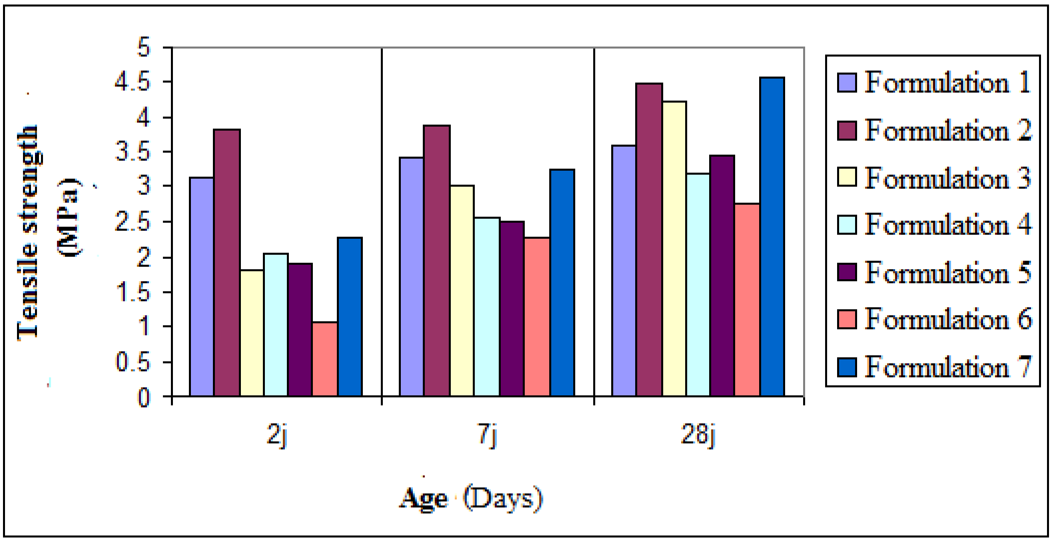

Figure 2. The influence of different formulations of concrete on its tensile strength as a function of age.

From all the above, we can affirm that the admixed pozzolanic concrete obtained by formulation n°7 [1] which will be indicated by BZ(2), is more advantageous than the other pozzolanic concretes and which developed the test program following:

-Tests on cement slurry to determine the super plasticizer dosage;

- Tests on mortar specimen 4*4*16cm3 for the optimization of dosage in additions

-Compression tests on a cubic specimen with a side of 15cm at different cures.

- Bending tests and ultrasonic tests on prismatic specimen 7*7*28cm3

II. Experimental study

This part concerns the application of formulation no. 7, which we considered to be the best among those examined in our study; To achieve this goal we performed the following experiment.

The experimental study was carried out in the laboratory of construction materials of the university of MUSTAPHA STAMBOULI of MASCARA.
We have developed the following test program:
- Test on fresh concrete:
• Measurement of concrete consistency.
• Measurement of the occluded area of the fresh concrete.
• Density of fresh concrete.
- Test on hardened concrete:
• Compression test on cylindrical specimen 16*32cm^2
• Tensile test on cylindrical specimen 16*32cm^2
• Bending test on prismatic specimen 7*7*28cm^3

II.1 Materials

II.1.1 Cement

The cement is a CPA 400, from the ZAHANA cement factory, these main characteristics are:

Physical properties of cement

Normal consistency ……………………………..….CN=25.5%
The Blaine specific surface…………………...…….SSB=3140 Cm^2 /g
Absolute density……………………….....………….Mv=3150Kg/m^3
The start of setting = 2h50.
The end of setting = 3h50.

II.1.2 Natural pozzolan:

It is a natural pozzolan of volcanic origin extracted from the bouhamaidi deposit of Beni saf, it has a humidity of about 30%, hence the need for prior drying.
The chemical analysis of this pozzolan is given in the table.

Table 4.Chemical composition of the natural pozzolan used in (%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	CaO libre	Perteau feu	Insoluble
33.31	11.82	6.66	24.14	3.38	1.24	0.42	0.27	0.8	17.60	98.86

Physical properties of pozzolan:

Absolute density ………………………………………………………Mv = 2.59g /cm3
Maximum fineness ……………………………………………………<80 µm

(a) (b)

Figure 3. (a) pozzolana rock before crushing; (b) pozzolan powder after grinding.

Aggregate

We used fine sand and two types of gravel of classes (3/8) and (8/15), of a silico-calcareous nature. The grain size analysis of sand and gravel (3/8) and (8/15) is shown in the following graph.

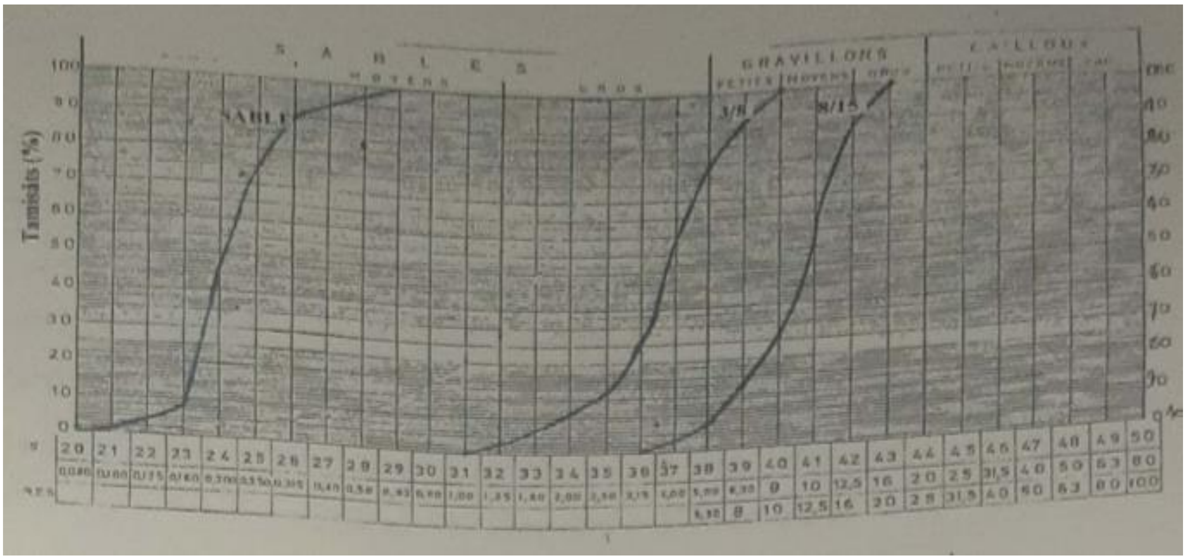

Figure 4. Particle size analysis of sand and gravel[13].

II.2 Sample preparation and test procedure

the concrete was made according to the "Dreux-Gorisse" method, the concrete intended for the making of test specimens of dimensions 7*7*28cm^3 for the characterization of the tensile strength in bending, and to characterize the compressive strength, we used cylindrical specimens 16*32cm^2 were mixed and prepared according to the procedures of standard NF EN 206/CN. we prepared two types of concrete, a reference concrete (concrete without pozzolana) ordinary portland cement CEM 1- 42.5N where the E/C rate = 0.5 and a concrete with natural pozzolan using an E/(C+A) rate was taken equal to 0.5 (the cement is partially replaced by 10% natural pozzolan).

When the mixing ends, the tests are carried out on fresh concrete, the specimens which are then maintained, will be unmolded after 24 hours, and kept in drinking water for 28 days at a temperature of 20 ± 2°C, before being tested on hardened concrete.

The two concretes thus obtained are designated by BT and B.Z(1).

Or :

(C+A): cement plus pozzolan;

W/(C+A): water to cement ratio plus pozzolan additions;

The concretes are formulated according to the following composition per m3:

- ♦ 425 Kg of binder;
- ♦ The class 3/8 and 8/15 aggregate used.
- ♦ 617 Kg of sand;
- ♦ The rate of mixing water was kept constant for all the mixes: E/(C+ A) = 0.5;

♦ Additive: super plasticizer, water reducer (SUPER CONTACT).

- dosage: 2%

- density: 1.20

Table (5) gives an overview of the composition of pozzolanic concrete;

Table 5. Composition of pozzolanic concrete per m^3.

Composants		Quantité en (Kg, %)
ajouts		10%
Ciment		420.8
sable		617
Gravier	3 /8	182
	8/15	1003
Eau		212.5
E/(C+A)		0.5

II.3 Discussions and interpretation:

II.3.1 Results of tests carried out on fresh concrete:

The results of the tests carried out on the pozzolanic concrete (substitution of 10%) B.Z(1) and on the reference concrete (concrete without pozzolana) B.T are grouped together in table (6):

Table 6. Physical test results.

Designation	Sag in (cm)	Air content %	The apparent density in (Kg /m^3)
B.T	4.8	3.2	2388
B.Z(1)	6	2.9	2382

According to this table (6) it can be seen that the addition of the addition of 10% of natural pozzolan requires an increase in the percentage of water, thus Boubakir [1] also found that the incorporation of 10% of the natural pozzolan increases the normal consistency by 8.5 to 8.7 cm.
The difference between the values of the consistency of our concrete and the concrete consistency of the formulation of Boubakir [1] are explained by the average quality of the superplasticizer admixture used in our concrete.
According to our experimental study and the formulation of Boubakir [1], we conclude that the consistency increases proportionally with the percentage of additions. This shows that the natural pozzolana has a large specific surface area and leads to a high demand for water to wet the entire surface. The result is confirmed by all the formulations studied in this work.

-Occluded air:

The rate of air occluded in the fresh concrete decreases with the percentage of the addition, this explains the filling role of the addition. This is confirmed by the study made by Boubakir [1], but the values obtained in our test are different.

- The density :

We notice that the density of concrete with additions is smaller than that of ordinary concrete, on the other hand the study made by Boubakir [1], presents an increase in the density of concrete with additions. This difference is probably due to the different constituents of the materials used in the two formulations.

II.3.2 Results of tests carried out on hardened concrete:

In the Compressive strength: we present the results of the compressive strength tests carried out on the specimens made up of the two concretes.
The values of these compressive strengths are given in table (7).

Table 7. Compressive strength values of B.T and B.Z(1).

Name / **Age (days)**	**B.T**	**B.Z(1)**
7 days	25.43	20.45
14 days	33.55	32.91
28days	38.10	42

To better understand the direction of the influence of pozzolana on the compressive strengths of pozzolanic concrete, and allow comparison with the control concrete, we present this influence in the form of a histogram given in figure (5).

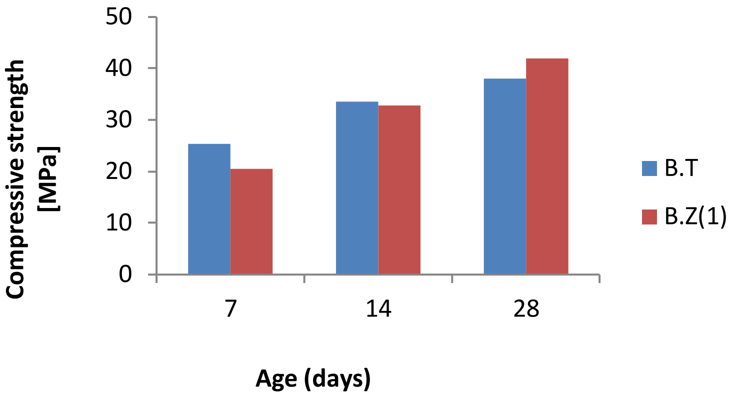

Figure 5.The influence of pozzolana as a substitute for cement on compressive strength.

III.Test spécimns

III.1 Compressive strength

We note according to the figure (5) that the resistances of all the concretes increase regularly with the age and does not present any fall of resistance, we also note that the resistance of concrete containing pozzolan increases in a continuous way with the age of concrete. It is comparable to that of ordinary concrete at young ages. This means that concrete based on pozzolanic cement at a dosage of 10% pozzolana gives, in the long term, significantly better mechanical strength than that of the control concrete.

It is important to see that the compressive strength of the control concrete at 28 days was approximated by concrete B.Z(1) with cements containing 10% of natural pozzolan but in this study the compressive strength of the control concrete at 28 days was moved away by concrete B.Z(1) with 3.9MPa. This is consistent with formulation No. 7[1] which treated concretes with cements containing 10% of natural pozzolan but in this study the compressive strength of the control concrete at 28 days was moved away by the BZ concrete(1) with a difference of 18 MPa.

The two pozzolanic concretes of the two formulations are designated respectively by: B.Z(1), B.Z(2)
B.Z(1): our pozzolanic concrete formulation.
B.Z(2): pozzolanic concrete of the chosen formulation
Comparison between the compressive strengths of concrete B.Z(1).and B.Z(2).
The evolution of the compressive strengths of our pozzolanic concrete is different from that of the pozzolanic concretes of the chosen formulation.
The pozzolanic concrete strengths of the two formulations are shown in Figure (6).

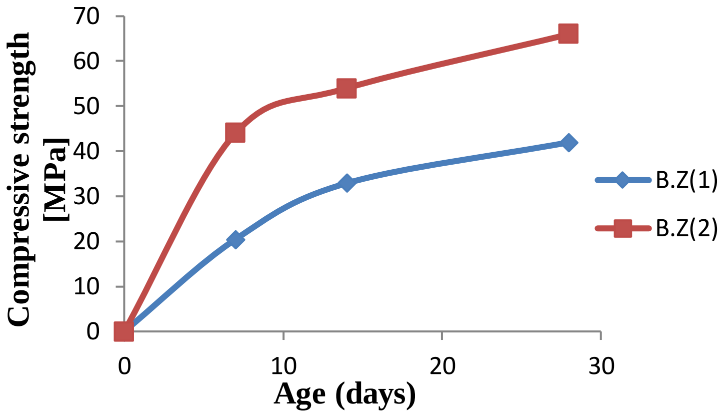

Figure 6. Evolution of the compressive strengths of the two concretes of B.Z(1), B.Z(2).

This figure shows that the compressive strength of pozzolanic concrete B.Z(2) increases continuously with the age of the concrete. It is comparable to that of BZ(1) concrete at a young age, but the resistance of BZ(2) greatly exceeds that of BZ(1) knowing that the same composition of BZ(2) has been applied but with materials different from those used in the development of BZ(2), the difference between the two strengths at 28 days for the two formulations is 24MPa. There are several factors which can have a great influence on the evolution of the mechanical properties in particular the resistance as the conditions of ripening, and in particular the ratio (W/C+A); recalling that BZ(2) was elaborated by a ratio (E/C+A)=0.35, on the other hand BZ(1) was elaborated by a ratio

(E/C+A)=0.5, which confirms the influence of this ratio on hydrated cement paste because it directly governs the initial spacing between the grains of cement and concrete in suspension in the mixing water. Several researchers have confirmed that the lower the W/C (for ordinary concrete) or (W/C+A) for (a concrete with additions), the more the porosity accessible to water decreases and the compressive strength increases. .

III.2 Bending Tensile Strength:

The results of the tensile strength measurements are given by the characteristic table (8) and represented graphically in figure (7):

Table 8. Flexural tensile strengths of concrete as a function of age.

Désignation / **L'âge (jours)**	**B.T**	**B.Z(1)**
7 jours	2,65	2,8
14 jours	3,20	3,75
28jours	3,95	4,20

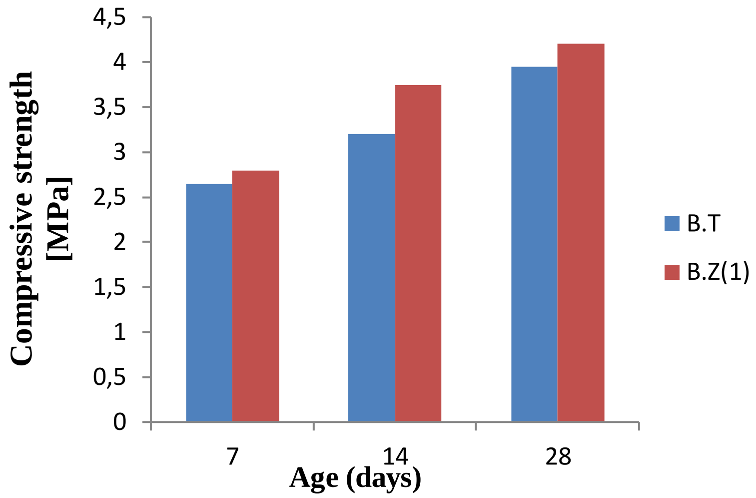

Figure 7. Flexural tensile strengths of concrete as a function of age (MPa).

Figure (7) indicates the influence of the incorporation of natural pozzolan on the flexural tensile strength of concretes at the age of 7, 14 and 28 days. We observe, as in the compressive strength, a regular increase in the flexural strengths of all concretes with age.

The pozzolanic concretes give good resistance compared to the control concrete. Indeed, the tensile strength by bending of a concrete containing 10% of natural pozzolana increases by 0.15MPa, 0.55MPa and 0.25 MPa at 7.14 and 28 days respectively .

Finally, note that the tensile strengths, for all the concretes, do not change much in the long term and especially from 20 days.

Comparison between the tensile strengths of concrete B.Z(1).and B.Z(2):

The evolution of the flexural tensile strengths of our pozzolanic concrete is different from those of the pozzolanic concretes of the Boubakir formulation [1] which we have chosen.

The flexural strengths of the pozzolanic concretes of the two formulations are presented in figure 8;

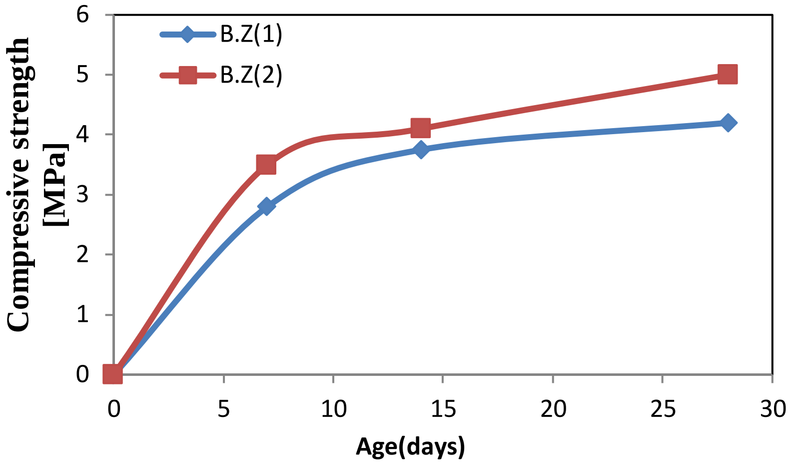

Figure 8. Evolution of tensile strengths by bending of concretes B.Z(1) and B.Z(2).

IV. Conclusion

This last part is essentially based on a comparison between two experimental studies, the first is our formulation and the other is the one we have chosen from among seven formulations. The results obtained by this comparative study can lead to the following conclusions:
• The substitution of 10% natural pozzolan in Portland cement generates a normal consistency of the concrete obtained which increases proportionally with the percentage of addition due to its large specific surface.
• the mechanical strengths of concretes B.Z(1) and B.Z(2) are close to those of the control concrete: pozzolanic activity is the main cause. the study also showed that concretes with 10% pozzolan have a very high resistance than B.Z(1). the differences between the values of the compressive strengths of the two formulations are explained by the difference in the materials used in the two formulations.
• it is possible to manufacture economical concretes based on pozzolanic cement, with good compressive strength. compressive strength.

Acknowledgements

In this part of the article the authors can express their gratitude to projects from the results of which the article has been written, or to people who have contributed to the results published in the article.

References

[1] L.Boubakir ; « Elaboration et étude d’un béton à hautes performances » ; Magister 1999 à l’université de Boumerdesse.
[2] L.Laoufi « Contribution et étude des caractéristiques physico-mécaniques des bétons à base de ciment pouzzolanique », Magister 2002,USTOMB.
[3] Y.Gharnouti ,T.Abadlia,R.Chaid ; « Effets des ajouts cimentaires ultrafins sur la durabilité et les propriétés physico–mécaniques des bétons » Séminaire national de génie civil SNGC2002- PROCEEDINGS, TOME1- Matériaux de construction présenté par ;laboratoire des matériaux min éraux et composite (LMMC).(université de Boumerdes), 2002.

[4] Aissa Asroun, Mohamed Bachir Bouiadjra, Habib Trouzine, « Influence des ajouts cimentaires sur le comportement des bétons» XXIIIème rencontres universitaires de Génie Civil 2005, risque et environnement, Laboratoire de Matériaux et Hydrologie Département de Génie Civil. Université Djillali LIABES, Sidi Bel-Abbès , Algérie.

[5] M.Drici, H.Klouche , « Valorisation de l'éffet de l'ajouts pouzzolanique de Beni saf sur le comportement physico-mécanique d'un béton de haute résistance » mémoire d'ingenier d'état ;Geni civil GCMO.(USTO), 2005.

[6] M.Mouli ; « Formulation d'un béton léger à base de pouzzolane » ; Doctorat d'état 2006, USTOMB.

[7] M.Mouli ; « Formulation d'un béton à haute performance à base de pouzzolane » ; Doctorat d'état 2006, USTOMB

[8] AFNOR EN 197-1, février 2001, Ciment - Partie 1 : Composition, spécifications and critères de conformité, Association Française de Normalisation AFNOR.

[9] Hester D., McNally C. and Richardson M., 2005. A study of the influence of slag alkali level on the alkali–silica reactivity of slag concrete, Construction and Building Materials, Vol 19 (9), 661– 665.

[10] Ghassan K. Al-Chaar, Mouin Alkadi and Panagiotis G. Asteris, 2013. Natural Pozzolan as a Partial Substitute forCement in Concrete. The Open Construction and Building Technology Journal,vol 7, 33–42.

[11] Khudhair M. H.R., Elyoubi M. S. and Elharfi A., 2017. Development of a new hydraulic binder (composite cement) based on a mixture of natural Pozzolan active 'PN' and Pure Limestone 'P,Lime': Study of the physical-chemical and mechanical properties- Journal of Materials and Environmental Sciences- JMES, Vol 8 (3), 902–910.

[12] Colak A., 2003. Characteristics of pastes from a Portland cement containing different amounts of natural pouzzolan, Cement and Concrete Research, Vol 33, 585–593

[13] AFNOR NF EN 196-1, 2006. Méthodes d'essais des ciments- Partie 1 : Détermination des résistances mécaniques.