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RESEARCH ARTICLE

STUDY OF A CONCRETE FORMULATION APPROACH WITH POZZOLANIC ADDITION BASED ON THE DREUX GORISSE METHOD: THE CASE OF MILLET POD ASH

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Abstract

Environmental issues have led construction researchers to work on reducing the amount of cement used in cement concrete, a material that is harmful to the environment because of its high CO_2 emissions. Their approach has been to use concretes in which some of the cement is replaced by pozzolanic materials. In this case, the binder used in pozzolanic concrete is an equivalent binder (cement + pozzolan). The difficulty lies in mastering the behavior of the equivalent binder so that it can be integrated into one of the concrete formulation methods. The aim of this study was to investigate the behavior of the equivalent binder (cement+ millet pod ash) for integration into the DREUX-GORISSE concrete mix design method. To this end, the effect of millet bean ash on the binder's strength class was studied, in order to adjust the quantity of water to maintain the desired workability. The absolute density of the millet husk ash is taken into account when determining the absolute volumes of the aggregates. After processing the results, the strength class of the equivalent binder is the product of the strength class of the cement and the pozzolanic activity index of the pozzolan used**.** The quantity of water required to achieve a given workability is the sum of the quantity of water required for workability in the case of cement alone and the product of the mass of pozzolan by a coefficient equal to 0.66.

Introduction:-

The construction industry is one of the world's most wealth-producing sectors, but also one of the main sources of greenhouse gas (GHG) emissions. Ever since the danger posed by these gases to the planet became known, researchers the world over have been busy finding various solutions to the problem in all sectors. In the construction sector, concrete, the most widely used material in the world, generates the most CO2 emissions. A closer look at its constituents reveals that cement, its most important input, is the main reason for its high carbon footprint, accounting for 98% of its emissions, according to a report by the Association Technique de l'Industrie des Liants Hydrauliques and the Union National des Producteurs de Granulats
(France). One solution is the use of eco-materials with the ability to:

1. have a low carbon footprint,
2. have the technical criteria required for building materials,
3. be part of a recycling policy,
4. be locally available, etc.

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In fact, researchers in the field of civil engineering are carrying out a great deal of research into these types of materials (Nguyen et al 2011; Zerbino et al 2011; Zain et al 2011; Ferraro et al. 2010; Cordeiro et al 2009; Nair et al. 2006). This has led to the emergence of a large number of materials that can be considered environmentally friendly or that have a tendency to contribute to the reduction of CO2 emissions. Among the solutions proposed by this research is the production of low-carbon concretes through the partial substitution of portland cement by materials whose production has a low carbon footprint. Most of these low-carbon substitution materials are agricultural or industrial wastes, including siliceous fly ash, blast furnace slag, silica fume, natural or artificial pozzolans, etc. (Stroeven et al 1999 ; Feng et al 2004 ; Safiuddin 2004, Alfred 1988; Cérézo 2005 ; Bharadwaj et al 2021).

With this in mind, research is being carried out on millet pod ash, an agricultural waste product available in the sub-region, which is sufficiently pozzolanic to be used as a partial substitute for cement in concrete. But a complete and specific formulation method would be needed. We have therefore decided to work in this study on the development of a specific formulation model that will take into account not only the characteristics of millet pod ash (CGM) but also their effects on binder behavior.

A number of studies have preceded ours, involving both artificial and natural pozzolans, particularly millet pod pozzolans. Thus Chaib et al (2015) studied the influence of natural pozzolan from the Bouhamidi deposit at 0%, 20%, 30%, 35%, 40% and 50% substitution on the mechanical strength of mortars based on compound cements. They found that at young ages, the difference between the strengths of pozzolanic mortars and the reference mortar is large, and decreases with time. Also, the higher the substitution rate, the lower the strength. Their study confirmed that substitution rates of 20% and 30% contribute positively to construction durability. (Zineb et al 2019) concluded that a volume substitution between 10% and 30% is optimal from the point of view of compressive strength and Young's modulus following their study of natural pozzolan from Béni-saf.

(Bouhamou et al 2008) have shown that for pozzolanic-substituted concretes, increasing water content has a reducing effect on mechanical strength.

Based on this information, we carried out a number of tests, including determining the density of millet pod ash and compressive strength tests on test specimens. The results enabled us to establish a methodological approach to the formulation of concrete with pozzolan.

Materials And Methods:-

Materials:-

To carry out our various tests, namely the absolute density test, the standardized consistency test and the compressive strength test, we produced ash from millet pods from northern Benin, more precisely from the commune of Kouandé. We also used salt 0/4 from the Dèkoungbé quarry (Abomey-Calavi, southern Benin) and Bouclier CEMII 42.5 cement.

Figure 1:- below shows the grading curve for the sand used in this study:

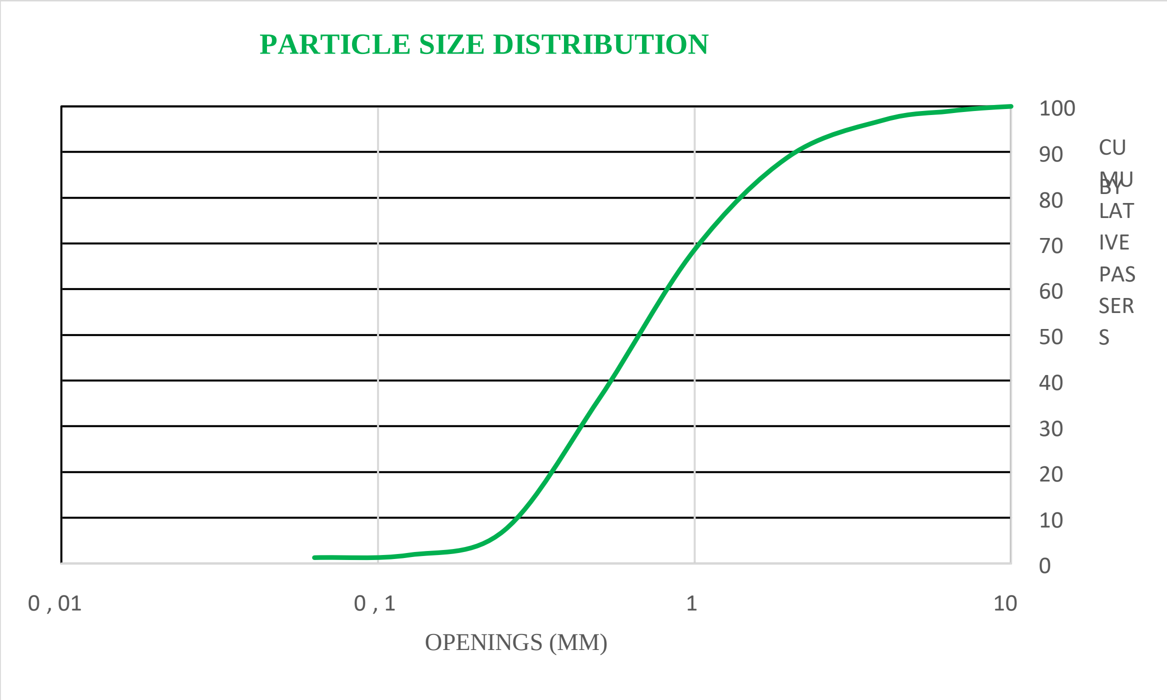

Figure 1:- Grading curve for the sand used.

2.Pozzolan production

Based on the bibliography, we opted for ashes produced between 500 and 700°C, as the available equipment was unable to maintain a constant temperature. For the calcination equipment, we used clay canaries, placed on a charcoal hearth containing charcoal embers, and by regularly measuring the temperature using an industrial laser thermometer, we lowered or fanned the fire to maintain the temperature within the set range.

Analysis Methods:-

a.Standardized consistency test

For this test, carried out in accordance with standard NF EN196-3, we determined the water content required to obtain a normal consistency (i.e. a 6±1 *cm* of a Ø=10mm probe under a 300g load without momentum) for cement alone and for cement/ash mixes with 5, 10, 20 and 30% ash.

b.Mortar compositions and mechanical testing

For the purposes of our experimental study, we formulated 4 types of mortar M0, M1, M2 and M3, each with mass substitution rates of 0%, 10%, 20% and 30%. With M0, our control mortar was formulated in accordance with standard NF EN 196-1. Water quantities were determined using a formula derived from the standardized consistency test.

Table 1:- Mortar composition.

Mortar	Cement (g)	Pozzolan (g)	Water (g)	Sand (g)
M0	450	0	225	1350
M1	405	45	255	1350
M2	360	90	284	1350
M3	315	135	314	1350

Six (06) cubic specimens with sides of 4 cm are produced for each formulation. The specimens are kept in a bath in the laboratory for up to 28 days before being subjected to compression testing using a press meeting the requirements of standard EN 196-1.

Results And Discussion:-

1.Absolute density

The absolute density of the millet pod ash produced is 2.256. This value is lower than that found for a natural pozzolan by Mokhtaria et al (2009), which is 2.75. The absolute density of a paper mill fly ash determined by SEGUI (2011) is 2.85. This value is also higher than the density of millet pod ash. Both natural pozzolan and paper mill fly ash are finely ground products, whereas CGM has not undergone any prior grinding. This justifies the difference in density. The density of CGM is lower than that of cement, which increases the absolute volume of the binder and reduces the absolute volume of the aggregates.

2.Standardized consistency

The table below shows the results of the standardized consistency test and shows the evolution of water demand according to the substitution rate.

Table 2:- Results of standardized consistency tests.

	Mix 0	Mix 1	Mix **2**	Mix 3	Mixture 4
Cement mass (g)	500	475	450	400	350
Pozzolan (g)	0	25	50	100	150
Binder (pozzolan cement) in g	500	500	500	500	500
P/L (%)	0%	5%	10%	20%	30%
Water mass (g)	157	173,5	190	223	256
E/L	**0,314**	**0,347**	**0,38**	**0,446**	**0,512**
d (cm)	7	5,5	6	5,5	6,5

It can be seen that water demand increases in proportion to the millet pod pozzolan content. This results in water contents of 0.314 and 0.974 respectively for cement and CGM to achieve normal consistency. The water demand was considerably higher than for cement, which could be explained by the greater specific surface area of CGM. From this we deduced a formula for adjusting the water content to ensure the same workability, whatever the substitution rate. This is :

$$\boldsymbol{MEau} = \boldsymbol{M0Eau} + \boldsymbol{0,66Mpouzzolane} \quad \text{(eq01)}$$

$Avec$

M_{Eau}: $Massed'eautotale$ à $ajouteraumortierpouzzolanique$

$M0_{Eau}$: $massed'eauprévuepourunmortiernormalesanspouzzolane.$

$M_{pouzzolane}$: $Massedepouzzolanedansleliant$ $équivalent$

a) 3.Compressive strength test

The figures below show, respectively, the evolution of compressive strength and strength activity index according to the substitution rate:

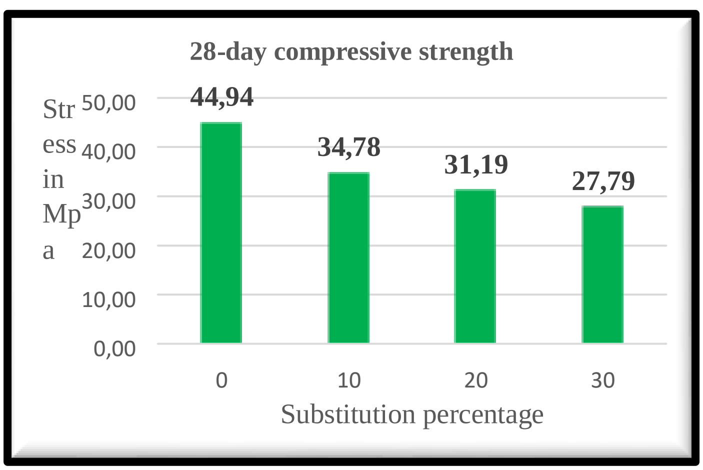

Figure 2:- Evolution of compressive strength as a function of substitution percentage.

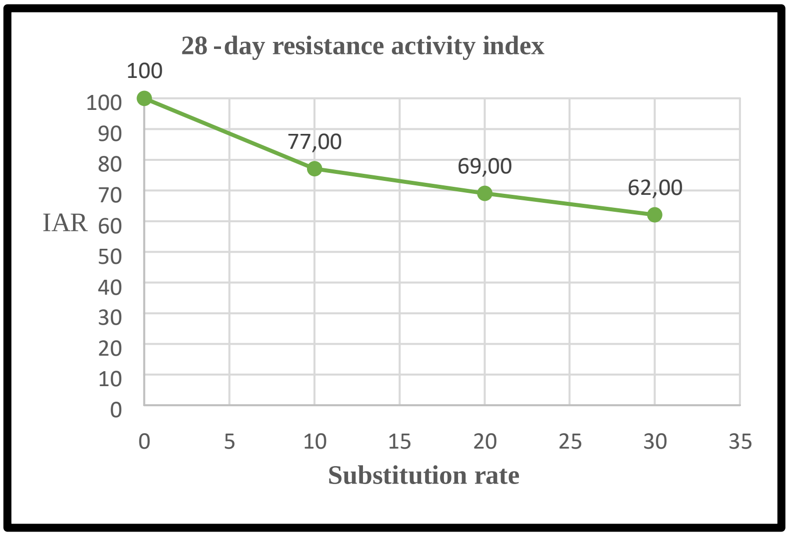

Figure 3:- Strength activity index for pozzolanic mortars.

According to these results, at equal consistencies, compressive strength at 28 days of age decreases as the percentage of cement substitution by pozzolan increases. The decrease in strength is easily explained by the set-retarding effect of pozzolan in a cementitious matrix. For 10%, 20% and 30% substitution, we have Resistance Activity Indices of 77%, 69% and 62% respectively.

4.Equivalent binder strength class

The results of the compressive strength test and the pozzolanic activity index were used to establish the equation for the strength class of the equivalent binder. Let σ'_c ; $\sigma'_l et IAR$ respectively compressive strength class of cement; compressive strength class of pozzolanic binder (cement + pozzolan) and pozzolanic activity index. $\boldsymbol{\sigma'_l = \sigma'_c . IAR}$ (eq02)

5.Methodological approach to formulation

The methodological approach is based on the DREUX-GORISSE concrete formulation method for ordinary concretes. We have introduced new equations to take into account the effects of the millet pod pozzolan we studied.

a.Base data selection

In this part, in addition to the Dreux-Gorisse method, we will have to choose the substitution rate f.This choice must be made within the scope of our study, i.e. 0% <f<30%.

b.Determining the L/E ratio

When formulating concrete with a cementitious matrix containing CGM, the C denoting cement dosage is replaced by L for the equivalent binder (Cement + CGM). Bolomey's formula for determining binder dosage thus becomes

$$fc_{28} = G x \sigma'_l \left(\frac{L}{E} - 0,5\right) \quad \text{(eq03)}$$

With$\sigma'_l = \sigma'_c x IAR$

fc_{28}Average desired compressive strength

σ'_c The true class of cement at 28 days

L: equivalent binder dosage (in Kg/m^3)

E: total water dosage on dry material (in litres/m^3)

G: granular coefficient

$\boldsymbol{IAR}$Coefficient dependent on the percentage of substitution, the values of which can be found in the table.

c.Determination of the quantity of binder, pozzolan, cement and water (L, P, C and E) After determining L/E, L is determined on the Dreux chart. The ordinate values are taken as L/E values, and the dosages are those in equivalent binder (cement + CGM).

As soon as L is known, we draw E, P and C.

With
$L = P + C$;$P = fxL$;$C = L(1 - f)$ (eq04)
f: The substitution rate
L: Equivalent binder dosage in Kg/m^3
C: Cement dosage in Kg/m^3
P: CGM pozzolan dosage in Kg/m^3
E: Water content in Kg/m ^{3}

d.Water dosage adjustment

1. Once E has been determined, it is corrected according to the size of the largest aggregate.
2. In addition to this, a correction will again be made to satisfy the additional water demand of the CGM. As the dosage obtained Ec after the previous correction is obtained considering the water demand of the cement, this correction taking into account the water demand of the CGM will be made according to the formula below:

$$\boldsymbol{E} = \boldsymbol{EC} + \mathbf{0},\mathbf{66} Mpouzzolane \quad \text{(eq05)}$$

This last adjustment will have the effect of offering the same workability as that expected for ordinary concrete with Ec.
The water content of dry materials is thus determined. However, care must be taken to take account of the water content of the aggregates when determining the mixing water to be added.

e.Determining aggregate mass

For this step the formula becomes

$$V_T = V_L + V_G = 1000\gamma \quad \text{(ep06)}$$

$V_G = 1000\,\gamma - V_L$
With

$$\begin{cases} V_L = V_C + V_{CGM} \\ V_C = \frac{C}{3,1} \\ V_{CGM} = \frac{P}{2,256} \end{cases} \quad \text{(eq07)}$$

V_L: Absolute binder volume
V_C: Absolute cement volume
V_P: Absolute volume of CGM Pozzolan
V_G: Absolute volume of all aggregates (sand, gravel, chippings, etc.)
If g1, g2, g3 are the absolute volume percentages of the aggregates obtained from the analysis of the grading curves. The absolute volumes of each aggregate are calculated by:

$$\begin{cases} V_{g1} = g_1 x V_G \\ V_{g2} = g_2 x V_G \text{(eq08)} \\ V_{g3} = g_3 x V_G \end{cases}$$

If d_1 $d_2 d_3$ are the absolute densities of aggregates 1, 2 and 3 respectively, the masses of each are:

$$\begin{cases} M_{g1} = d_1 x V_{g1} \\ M_{g2} = d_2 x V_{g2} \text{(eq09)} \\ M_{g3} = d_3 x V_{g3} \end{cases}$$

Once all these steps have been completed, we obtain the mass composition of a cubic meter of millet pod ash pozzolanic concrete (Sand + Gravel + Cement + Millet pod ash + Water) with the characteristics set for the concrete (workability, compressive strength, final compactness).

Conclusion:-

At the end of this study, we were able to propose an approach for formulating concretes with pozzolanic substitutions. This formulation approach is based on that of DREUX-GORISSE for the formulation of ordinary concretes. A close analysis of this method revealed the following:

1. in determining the E/L ratio, the strength class of the binder is taken into account and this strength class will be affected by the incorporation of pozzolan as a partial replacement;

2. When formulating concrete, workability is one of the most important basic data that determines its placement, so it must be kept constant even after the ash has been incorporated;
3. and in determining aggregate dosages by absolute volume, the absolute density of the binder is taken into account.

.4

The main changes incorporated in this approach are the determination of the quantity of equivalent binder, which takes account of the pozzolan's reactivity, and the assessment of the quantity of water. Once the quantity of equivalent binder is known, the quantity of pozzolan is determined on the basis of the desired substitution rate. This rate may not exceed 30% for this method. For the determination of aggregate volumes, the method integrates the volume of pozzolan used, based on its density. As for the range of the substitution rate, limited to 30% for this study, we will see in future studies whether it can be extended beyond this.

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