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RESEARCH ARTICLE

LOCAL FORMULATION OF HIGH PERFORMANCE CONCRETE USING CALCINED KAOLIN: CASE OF CHAD

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Abstract

The main aim of the work carried out in this article is to investigate the local formulation and characterization of metakaolin and superplasticizer-based high-performance concretes (HPCs) in Chad. Five types of concrete were formulated, including one control and four others containing metakaolin as a cement substitute in proportions of 5, 10, 15 and 20%. Four concrete properties were evaluated: fresh concrete (density and slump test) and hardened concrete (density and compressive strength at 3, 7, 14 and 28 days), in order to assess the influence of metakaolin in the different compositions. The results obtained show that: (1) the concretes tested have almost identical workability, with a standard deviation of 0.62; (2) in the fresh state, the control concrete has a higher density, justifying the lower mass of the metakaolin, whereas in the hardened state, the density of the high-performance concrete with 20% metakaolin is higher; (3) the high-performance concretes show greater kinetics in the evolution of compressive strengths. Simple compressive strengths are observed on HPCs with a maximum of 70.2 MPa on 15% metakaolin concrete, compared with a minimum value of 51.4 MPa on control concrete. Overall, the present work has highlighted the pozzolanic activity between metakaolin and lime released during cement hydration to produce hydrated calcium silicates, and the deflocculating activity of cement grains by the superplasticizer, with the joint aim of improving concrete mechanical strengths and durability.

Introduction:-

Concrete, the world's most widely used composite construction material, is generally defined as a mixture of binders (cement, lime), aggregates (gravel, sand), water and, where appropriate, additives, in the right proportions.

At the end of the 19th century, a number of engineers became interested in concrete formulation methods to improve its properties. In recent decades, scientific studies have been carried out with the aim of making concretes more

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economical and durable. It was in 1980 that the means of making concrete more compact by adding microparticles and plasticizers was discovered, leading to the development of High-Performance Concrete (HPC). Aitcin, P.C. (2001) later asserted that the quest for high performance involved reducing the porosity of concrete (its percentage of voids).

According to DE Larrard and Malier (1992), HPCs are characterized by high compressive strength (>50Mpa at 28 days), good workability and a very dense microstructure observed by Scanning Electron Microscope (SEM). Performance is enhanced by the use of water-reducing superplasticizers to ensure workability, and by the addition of ultra-fine mineral additives. Economic constraints and the desire for research led to experimentation and the addition to concrete of a new, more widespread and important mineral addition: metakaolin or calcined kaolin.

Metakaolin is an ultra-fine mineral addition obtained by calcining kaolinite at a temperature of between 650 and 850^{o}C, depending on the purity of the kaolin clay used, and has very high pozzolanic activity. During this transformation, the sheets spread apart, releasing free water from the inter-sheet, as can be seen in the SEM photographs collected by Rackel S.N. (2011).

Fig 1:-SEM photographyof kaolinite (Rackel, 2011).

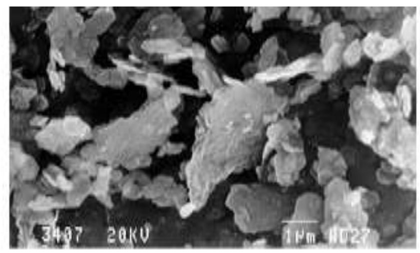

Fig 2:-SEM photography of metakaolin (Rackel, 2011).

The properties of metakaolins are highly dependent on their specific surface area, particle size and mineralogical composition (Perlot, 2000). According to Mbessa M. (2000), metakaolin essentially plays a dual role in concrete: a granular role by filling the granular interstices inaccessible to cement grains and a pozzolanic role by reacting with the lime released during the hydration of the cement to give hydrated calcium silicates (C-S-H), contributing to the increase of the mechanical strength of the material.

In Chad, the best known Kaolin deposits are those of Aboudeia in the Salamat region and in the south of the country: East of Pala, near Kelo, in the village of Maïssou 75 km from Moïssala and also near Mbaïnamar (Kusnir, 1989). No in-depth study has been carried out to evaluate the quality of these materials and it is in this context that it is necessary to carry out research to identify the virtues it confers on concrete. According to Asbridge et al. (1996), the additional cost associated with the use of metakaolins is amortised if the overall cost of the structure is considered. Knowing that Chad is a country that aspires to development like several other African countries, the study of the formulation of BHP therefore becomes important to obtain a resistant concrete based on local products and necessary and available additions such as metakaolin.

Material and Method:-

Material:-

The materials used are cement, aggregates, superplasticizer, metakaolin and water:

-The cement used is a Portland compound cement, with the designation CEM II 42.5R, consisting of 80 to 94% clinker and coming from the CIMAF CHAD cement plant. Its chemical, physical and mechanical characteristics have been given by the manufacturer in the technical data sheet;

-The aggregates used are fine sand, coarse sand and gravel. The sands come from the Chari River while the gravel comes from the blasting and crushing of granite exploited by the company ‘’Société Nouvelle d'Etudes et de Réalisation (SNER)’’ at the Hadjer Lamis quarry;

-The superplasticizer used is Sika ViscoCrete® Krono-20 HE. It was ordered in Douala, Cameroon from the company SIKA, which produces construction materials and admixtures. The specifications have been given in the technical sheet;

-The kaolin ordered for the study comes from the Salamat region. The metakaolin obtained is the result of the traditional calcination at 750°C for 5 hours of this kaolin in the oven with a temperature rise of 5°C/min. It was characterized by its density, its specific surface area and its particle size.

Method:-

The working procedure consisted of initially defining a formulation method for the manufacture of concrete. Then, it was a question of choosing and characterizing all the materials used. The composition of the control concrete (CT) containing no metakaolin was carried out in order to be able to follow the characteristic evolution of the concretes which incorporate it at different rates as a substitute for cement. The complete composition of the concrete is defined in Table 1.

Tab 1:- Composition for 1m^3 of concrete.

Constituent	Cement (Kg/m^3)	Metakaolin (Kg/m^3)	Gravel (Kg/m^3)	Sand (Kg/m^3)	Superplasticizer (Kg/m^3)	Water (Kg/m^3)
CT	400	0	1237	699	12	140
C5	380	20	1237	699	12	140
C10	360	40	1237	699	12	140
C15	340	60	1237	699	12	140
C20	320	80	1237	699	12	140

The test tubes are made in cylindrical molds measuring 16x32 cm (6.5dm^3). The molds were filled by medium vibration and the test pieces were kept in tanks containing drinking water after 48 hours. The tests in the fresh state and in the hardened state were therefore carried out respectively on the concrete before and after the preparation of the specimens.

Results and Discussions:-

Fresh condition:-

Density

The densities are very close to the theoretical density calculated during the composition of the granular skeleton. Which proves that the formulation was indeed 1m^3 of concrete. However, a decrease in the apparent density is observed as a function of the increase in the metakaolin substitution rate. This is explained simply by the fact that for equal volume, cement weighs more than metakaolin. Therefore, the more the substitution rate increases, the less the concrete weighs in its fresh state and the densities decrease. With an average of 2462.6 kg/m^3 and a standard deviation of 6.41, the densities are close to each other. However, the concrete with the greatest apparent density in the fresh state is the control concrete and the least dense is that which has 20% metakaolin as shown in the graph in Figure 3.

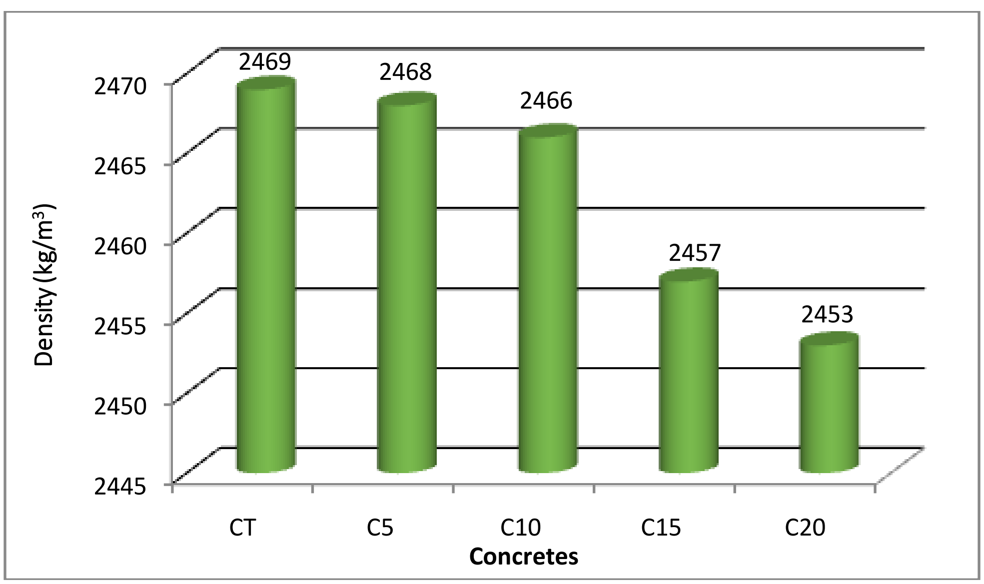

Fig 3:- Representative graph of the densities of concrete in the fresh state.

Slump test

The concrete slump values vary very little and remain in agreement with the formulation hypotheses. The formulated concretes have slump classes S4 and are considered fluid. Given the small quantity of water used, this fluidity is undoubtedly obtained thanks to the fluidifying role played by the superplasticizer. As also well shown by Gruber et al. (2001), the slump decreases as the metakaolin content increases because its particles are very fine and fill the voids found in the concrete. The average subsidence is 20.12 cm and its standard deviation from the values obtained is 0.62. Figure 4 shows a visual inspection of the sags in relation to each other.

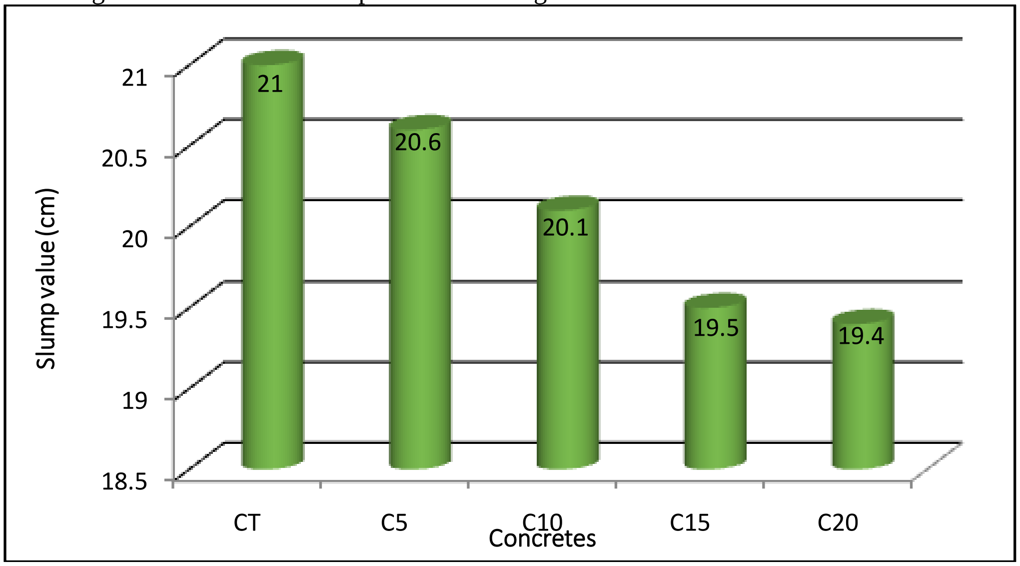

Fig 4:- Representative graph of the slump test in the fresh state.

Hardened state:-

In the hardened state, physical and mechanical tests are carried out at different ages (3, 7, 14 and 28 days) to see their performance progression over time.

Density

With an average density in the hardened state of 2544.2 kg/m^3 and a standard deviation of 33.57, the concretes are of normal type. The densest concrete is that which contains 20% metakaolin and the least dense is the reference concrete. This is explained by the fact that the addition of metakaolin causes a pozzolanic reaction which densifies the concretes. The compactness increases gradually with the metakaolin substitution rate. It therefore increases from the control concrete to that containing 20% metakaolin as shown in Figure 5.

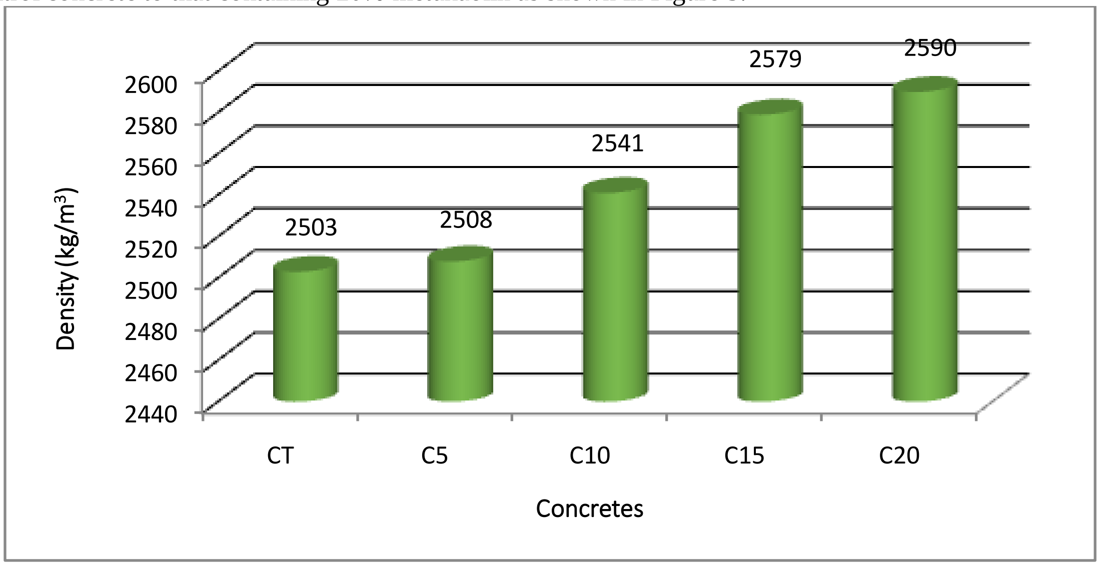

Fig 5:- Representative graph of the densities of concrete in the hardened state.

Compressive strength
The compressive strength values of concrete are given in table 2.
Tab 2:- Compressive strength values of concrete.

Concretes	Compressive strength at 3 days (MPa)	Compressive strength at 7 days (MPa)	Compressive strength at 14 days (MPa)	Compressive strength at 28 days (MPa)
CT	17.7	23.1	26.4	51.4
C5	15.9	24.2	28.8	55.6
C10	16.0	27.3	34.3	62.6
C15	18.2	33.0	41.1	70.2
C20	17.1	30.1	33.7	56.4

These results show that for all concretes, 3-day compressive strengths are high and vary little. The evolution of strength over time for the reference concrete is driven by the hydration rate of the cement. For concrete containing metakaolin, it depends on both cement hydration rate and pozzolanic reaction kinetics. However, from 7 to 28 days of wet curing, strengths increase with different substitution rates. Concrete incorporating 5% metakaolin, although slightly higher, shows similar results to the reference concrete at all ages, as all the metakaolin is consumed during cement hydration and more portlandite reacts. As a result, there is no longer any metakaolin capable of establishing the pozzolanic reaction at later ages. However, results show that for substitution rates of 10 and 15%, strength values become very high at 28 days (figure 6).

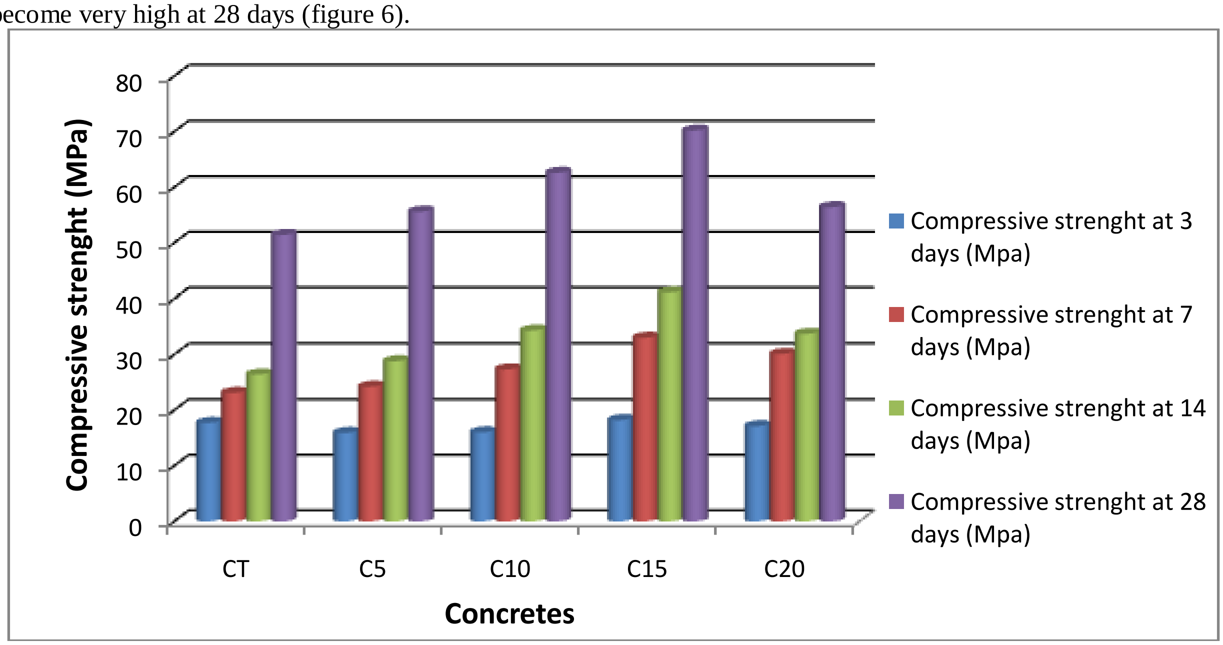

Fig 6:-Compressive strenght diagram.

The composition which presents the most significant increase is the one whose substitution rate is 15%. However, concrete which contains 20% metakaolin experiences a progressive drop in strength compared to other concretes because with a raised rate, the metakaolin grains which have not been able to react pile up and enter an inert phase making the concrete less compact. . We therefore note that the incorporation of metakaolin at a controlled rate improves the compressive strength of concrete at 28 days as clearly shown by Khatib (1996) in his work. But unlike the results obtained by DOUAMBA (2016) where the mechanical resistances changed considerably at 7 days, it is noted that at 28 days, our results become more relevant, with a lower quantity of cement than its own.

The desired strengths were achieved for all the concretes (more than 50 MPa at 28 days), which demonstrates that it is perfectly possible to formulate BHP with locally produced materials. The curves of evolution of the compressive strengths of the different concretes present the same appearance except for C20 as shown in Figure 7.

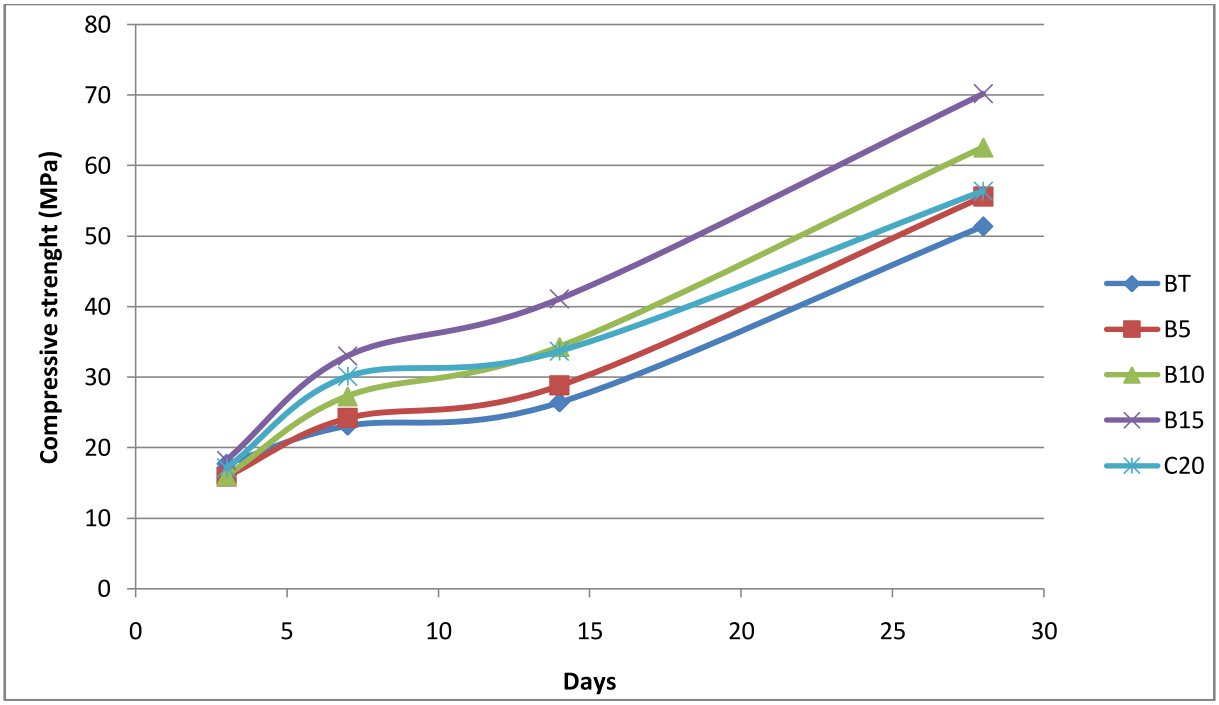

Fig 7:-Compressive strenght curves.

Conclusion:-

In view of the results obtained, we can safely say that the combined use of metakaolin and superplasticizer produces particularly fluid, resistant concretes while maintaining a low W/C ratio. Clearly, then, metakaolin has a positive influence on the formulation of high-performance concretes. With the kaolin reserves available in Chad, it would be possible to formulate, under local conditions, more efficient concretes capable of meeting people's needs in terms of cost, strength and durability. This process will enable us to reduce the quantity of cement, the most expensive material in concrete. Not only will the strengths demanded by HPCs be achieved, but the overall cost of producing $1m^3$ of concrete will be considerably reduced.

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