Characterization of material for cement production in Mbuji-Mayi area (RD Congo)

Matamba Jibikila Raphael [1] , Pirard Eric [2]

[1] *PhD student and Mining Ir, Mining Department, University of Mbuji-Mayi. RD Congo*
[2] *GeMMe Sector. University of Liege, Belgium.*

ABSTRACT

Although the City of Mbuji-Mayi (DR Congo) is rich in limestone and clay deposits, cement and other building materials are still being imported sometimes by plane from Kinshasa, Zambia and Tanzania. A consequence of this situation is low consumption of cement and concrete (less than 1kg per capita) and a lack of modern and sustainable infrastructures. Our study provides a qualitative assessment of all cement raw materials available in the region, including limestone and clay in order to produce hydraulic binder with optimized technical and environmental performances. Chemical and mineralogical characterizations were done using XRF spectroscopy and X-ray diffraction (XRD). Thermal analysis, electron microscopy, and mechanical characterizations are planned to assess the performance of the concrete and mortar manufactured with the binder produced. Finally, the ultimate goal is to produce a local hydraulic binder whose physical and mechanical characteristics are similar to those of Portland cement, but whose production is expected to consume less energy and emit less CO2.

Keywords: Local binder, environment, performances.

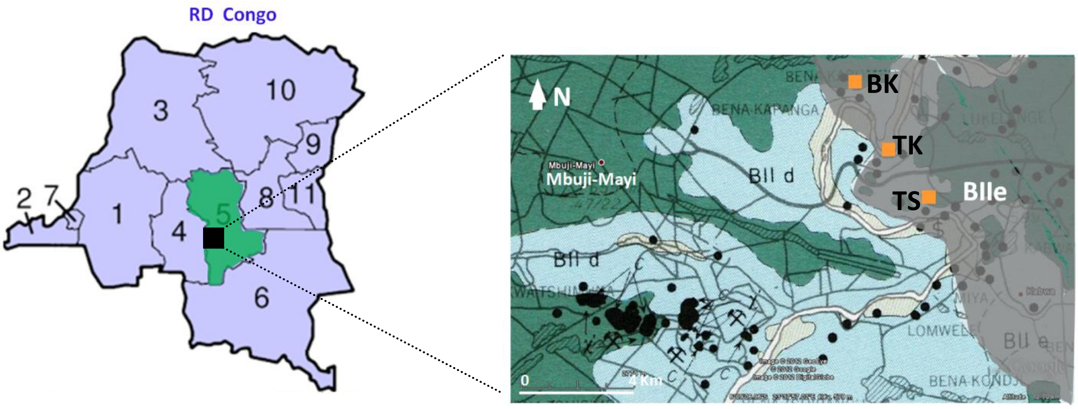
Matamba Jibikila Raphael: r.matamba@doct.ulg.ac.be
Pirard Eric : eric.pirard@ulg.ac.be

Introduction

The per capita cement consumption in Sub-Saharan Africa is the lowest in African continent. It stands at 92 kg while the North African average is 553 Kg. The DR Congo with a population reaching 70 million people has a cement production capacity of 0.5 Mta lagging behind Cameroon whose cement production capacity is of 1.7 Mta for 20.1 millions habitants [3]. There are currently several projects to increase the cement production capacity in DR Congo Three quarter of these projects concern existing plants. These cement or clinker plants are located very far from some regions such as Mbuji-Mayi which is in the centre of the country. The cement price in this region is five times expensive compared to the price at the cement production sites. However, the Mbuji-Mayi city is rich in limestone and clay deposits and there is unanimous agreement that cement or other hydraulic binders need to be developed in this region. The production of such binders requires large amounts of energy and is a source of greenhouse gas emissions. 100kWh of electrical energy are required to produce one ton of cement while 800kg of CO_2 is emitted during the production process [9]. Although traditional Portland cement clinker formation may be made more efficient with the energy requirements in the different steps identified and minimized by introducing of energy-efficient dry-process kiln systems and even if quantity of CO_2 released is reduced because of the reduced thermal energy requirements, the composition of the cement is not radically changed and the quantity of $CaCO_3$ to be decarbonated remains similar. Many researches are being done to replace limestone in the feed mixture while ordinary Portland clinker is gradually replaced by some supplementary cementitious materials (SCMs). Such actions can be encouraged when those replacing materials are locally available or not too expensive to import. Common SCMs include fly ash from coal combustion, blast furnace slags from iron production, silica fume, etc. No natural SCMs is available in the Mbuji-Mayi area and iron, glass or coal plants projects never existed. The remain option is to produce “eco-binders” that meets the needs of the local community. Belite cement and hydraulic lime were chosen given to the availability of the Mbuji-Mayi raw material (siliceous limestone and kaolinitic clay). Other types of cementitious binders such as Calcium aluminate cements (CACs), Calcium Sulfoaluminate (CSA) cements or alkali-activated binders gain interest to replace ordinary Portland cement. But some disadvantages still limit their widespread use. For example CAC and CSA are expensive compared to Portland cement, with the cost related directly to the limited supply of bauxite, which is the main source of alumina for CACs or CSA production [4]. Hence, we present in this paper preliminary results of Mbuji-Mayi supergroup material characterizations, and the ways to produce a local binder with optimized technical and environmental performances using metakaolin.

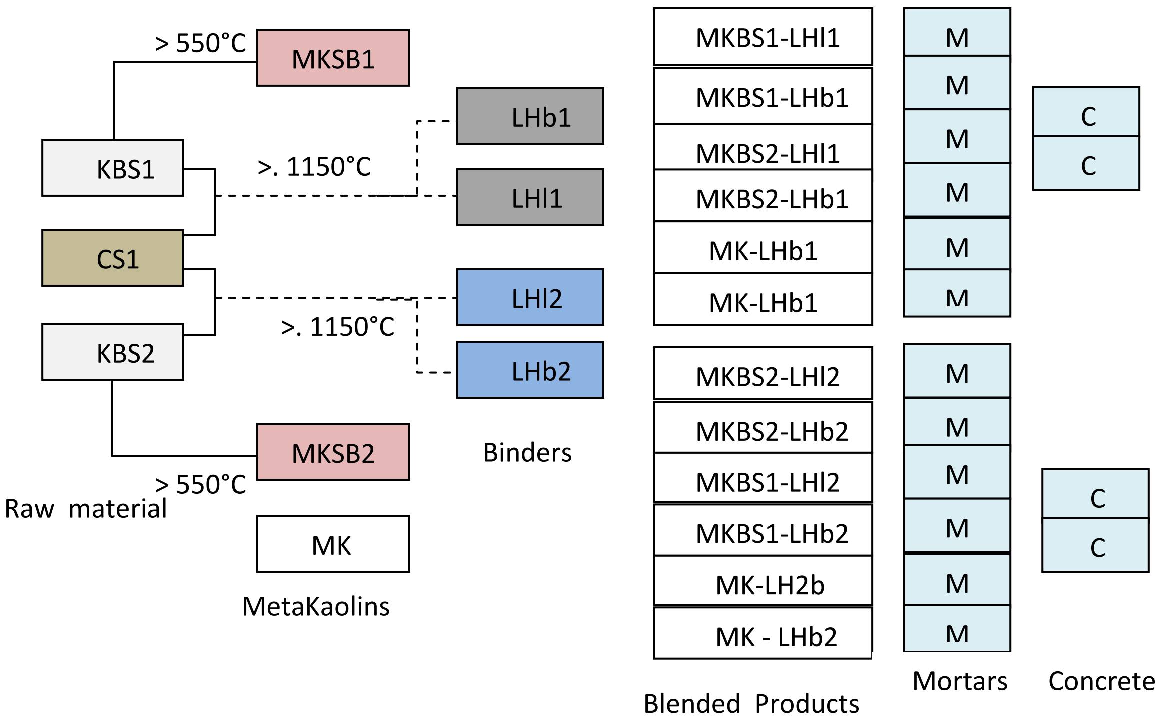
Materials and Method

Mbuji-Mayi Limestones are located in the Mbuji-Mayi Supergroup which is a set of sedimentary rocks. Several samples were collected from outcrops sites and artisanal quarries BK, TK and TS Figure 1. Chemical results were performed using X-ray fluorescence spectrometry ARL 9400 Sequential XRF XP. Mineralogical characterizations were done using XR D8 Bruker advance. Results are shown for RM1 and TS13 samples. For the latter sample, qualitative and semi quantitative mineralogical analysis was done for the clay fraction. Kaolinitic materials play two roles here. First, they are mixed with limestone to prepare the kiln feedstock and the second role is to be used as pozzolanic materials when thermally activated (Metakaolin). Studies show that Metakaolin is a suitable material for application in hydraulic lime-based concrete as a pozzolanic addition and a substitution around 20% of hydraulic lime by Metakaolin seemed to give best results [1]. We collected two kaolinitic materials KBS1 and KBS2 in the northwest part of the Mbuji-Mayi city. KBS1 and KBS2 particle size analysis where done by image analysis and chemical analysis where performed using XR-fluorescence spectroscopy.



[Figure 1]. DR Congo Map with Mbuji-Mayi region location showing limestone zone (BIIe).

The flow-sheet operations are given at the [Figure 2]. CS1 is a siliceous limestone sample which is mixed with kaolinitic clay KBS1 and KBS2 in order to produce belite cement (LHb) and hydraulic lime (LHl) in the range of temperatures from 1150 to 1300°C. When burnt at these temperatures, we get LHb1 and LHb2 which are belite cement samples and hydraulic lime samples (LHl1 and LHl2). Physical, chemical, mineralogical and morpho textural characterizations are done on binders produced using Image analysis, SEM/EDS and XR spectroscopic techniques. Since these binders are mainly belite formed, they do not provide good performances in short and medium term, thus 10%, 20% and 30% of binders will be substituted by pozzolanic material (metakaolins) MKBS1, MKS2 and MK. The latter is a commercial Metakaolin. Finally, Laboratory mortars and concrete will be produced for mechanical tests at different curing times. The energy balance is evaluated for both belite cement and hydraulic lime in order to choose the binder that fits the local conditions.



[Figure 2]. Flow-sheet for LHb and LHl production.

Preliminary results and discussion

An oxide analysis of thirty eight BIIe samples was done using XR- Fluorescence technique. Results are presented on Figure 3. Globally, they are promising for cement or hydraulic lime manufacture. Given to these results, kiln feed can be prepared designed to a lime saturation factor between 75 – 85 per cent. It is in order to get low energy and low CO_2 savings binder. Many investigations showed that there is low CO_2 savings potentials (less than 10%) and the low strength development rate hampers the building productivity. In Mbuji-Mayi region, cement is a key construction material for the infrastructure development. There are several projects requiring specific cement quality. Many massive structures have to be constructed including dams structures one some rivers. We know that those kind of structures require low heat cements. These cements can be obtained may be by using concrete containing in some proportions fly ash or other SCMs or at least, a rich belite cement should be use. The latter option can be retained indeed, because for the moment, excepted burnt clays, no other artificial pouzzolana or supplementary cementing material is available in the region.

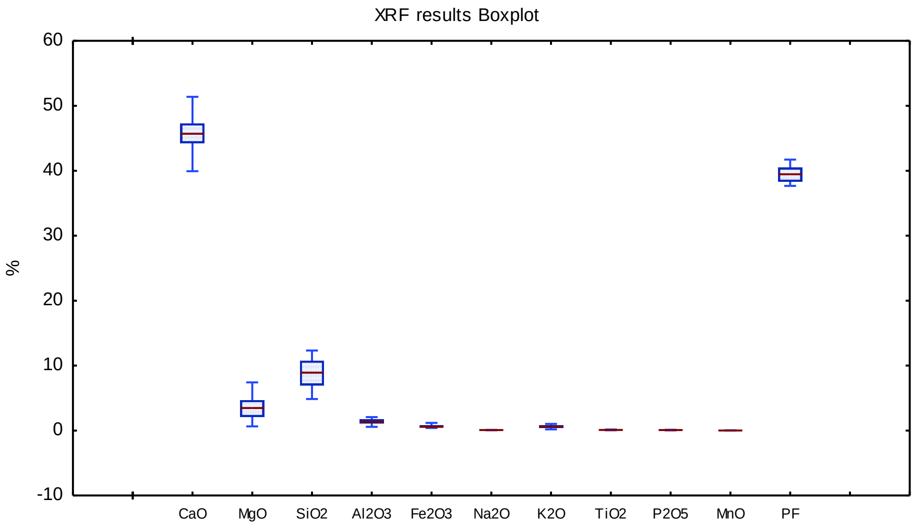


Figure 3. XRF box plot for 38 samples from BIIe group

Limestones show also an overall mean value of MgO content of 4%. We know that during clinkering process, Magnesia (MgO) is transformed to Periclase (MgO) which is difficult to hydrate or have a very slow hydration rate. This can cause cracking problem in hardened pasts after many years. However, studies related to the cooling speed of belite clinker on the effect of MgO (Periclase) showed that rapidly cooled clinker forms smaller alite and Belite crystals, exhibits faster strength growth during hydration, and is able to accommodate the hydration of Periclase [5]. The quenching process improves also the reactivity of the clinker and is based on the Lime saturation factor (LSF) ratio. Fig.4 [9] shows the effect of the quenching rate of clinkers of different lime saturation factor on their strength generation capacity. Alkali content is in sufficient average in raw materials. They play an important role in controlling clinkering temperature. K_2O when incorporated in C_2S can stabilize the α' phase when Na_2O is sometime indicate to contribute in increasing mechanical strength of corresponds cements. X-Ray diffraction results for two samples are shown in Fig. 5. it is a semi quantitative analysis. For both samples, the main crystalline phases are: calcite, and low quantities of quartz and dolomite. Quartz in the raw mix is not desirable. It can influence the clinkering process in a negative way. Some authors confirm that coarse quartz grains need more energy (time and temperature) to fully react with the involved minerals of the raw mix to form C_3S and C_2S [8] .Hence silica present as quartz is generally more difficult to combine as silica present as silicates [5].

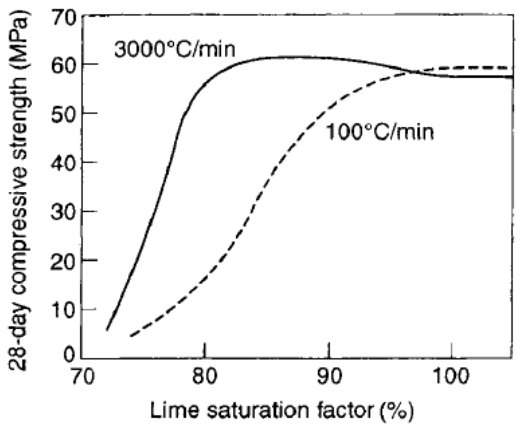
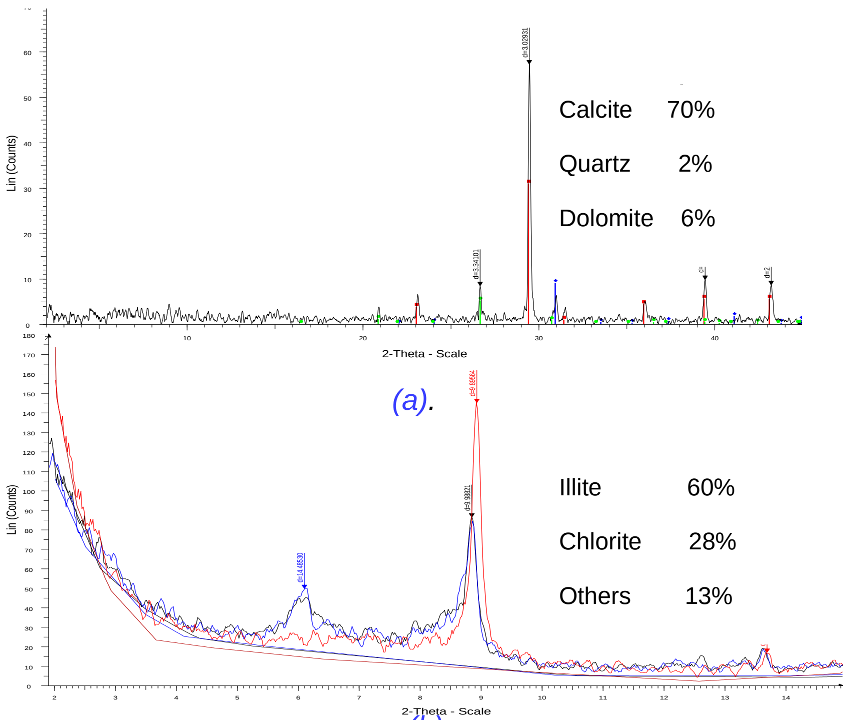


Figure 4 effect of the quenching rate of clinkers of different lime saturation factors on their strength generation capacity [9]

So in our case, we note that a big part of silica was carried by clay minerals present in argillaceous fraction of Limestone. XRD results shows that the main mineral present in the argillaceous fraction is illite. Hence, there will no major problem in any silica and lime combination to form silicates phases. The Figure 4 (b) shows the main mineral components in argillaceous fraction part of TS13 Limestone sample. Elements in the raw mixture can also have influence during clinkering process. In present results no discussion is considered at this level. But it will appear during burning and hydration process.



(b).

Fig. 4. XR Diffraction for RM1 (a) and argillaceous fraction of TS13 (b).

BIIe raw material can also be used for hydraulic Lime. They are siliceous limestone and the hydraulic lime feedstock should need the same raw mix composition. But for the hydraulic lime, the burning temperature should not exceed 1200°C. The main phases at this temperature are belite and aluminate phases. But due to the very low content of tricalcium silicate, commercial hydraulic lime with high mechanical resistance at the age of 28 days is HL5 (5 MPa). This is insufficient for some construction requiring high resistances. It is proved that the use of Metakaolin as an additive to HL produces a positive effect in term of strength improvements and substitution to hydraulic lime by 20% and 30% of metakaolin produced increased compressive strength .[11] . In this paper we took first two type of Kaolinitic material KBS1 and KBS2 in order to produce Metakaolin to be added to LHI. Particle size curves obtained by image analysis (OCCHIO 500 Nano) are given on Figure 8 and XRF chemical results in Table 2.

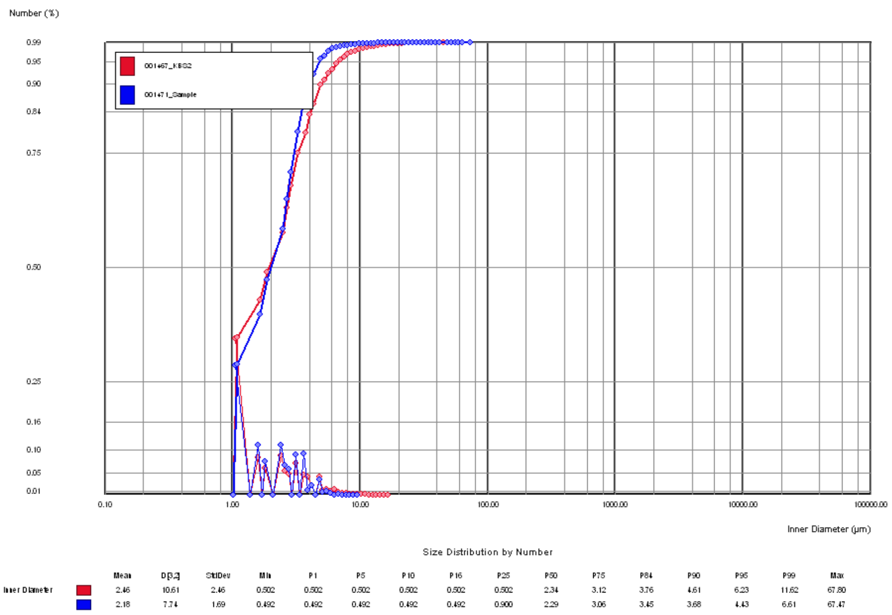


Figure 8. Particle size curves for KBS1 (blue) and KBS2 (red).

Table 1. XRF chemical composition of KBS1 and KBS2.

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
KBS2	54,12	1,68	32,43	1,84	0,01	0,28	0,12	0,03	0,30	0,08
KBS1	53,90	1,64	40,48	2,72	0,01	0,33	0,07	0,06	0,33	0,09

We notice that particles having a size (inner diameter) less than 4 microns represent 80% whereas in volume, the same percentage corresponds to particles with less than 40µm. This shows that particles are so fine that thermo chemical reactions will be achieved. But usually with particle size between 45µm and 9µm, chemical combinations take place without major problems [7]. These materials should have pozzolanic properties when thermally activated (calcination of Kaolinitic clays) over a specific temperature range. The product should react with $Ca(OH)_2$ to give highly resistant silicates and thereby improve the mechanical properties of hydraulic lime. Pozzolanic properties also depend on the chemical and mineralogical composition of primary kaolinitic clay as well as the particle size. Generally studies confirm that the overall amount of combined lime essentially depends mainly on the nature of the active phases; their content in pozzolana; their SiO_2 content; the lime/pozzolana ratio of the mix; length of curing; whereas the combination rate also depends on . The specific surface area (BET) of pozzolana; water/solid mix ratio; temperature. The Mbuji-Mayi Kaolinitic clays seem to have good properties to be used as pozzolanic material when calcinated. Chemical results given in table 1, are interesting for natural kaolinitic clay. Mineralogical compositions results obtained from other studies on Mbuji-Mayi clay material showed an overall good composition for Kaolinite content.

Conclusion

In this preliminary study, we can conclude that Mbuji-Mayi material including Limestones and clays are good for cement or other hydraulic binder production. Limestones are impure (siliceous) thus well indicated for these purposes. The average value of CaO is 44.5 %, MgO is less than 4 %; SiO_2 (10%), Al_2O_3 (2%) and Fe_2O_3 (1%). Main mineral in limestones are calcite, and in some proportions quartz and dolomite. The silica content in limestone is carried out by the argillaceous fractions (content). And we saw that this silica form is easy to combine during clinkering process. Clays material are also available in the region and those preliminary chemical results obtained prove that there are good for both raw feed mixture and artificial pozzolanic material when calcined over a specific range temperature. 80 % particle (in volume) has inner diameter less than 40 µm. These results seem to be good for a natural material. But further granulometric test will be performed in order to complete the image analysis technique. Belite cement and hydraulic lime are chosen due to sustainability purposes. The energy source is the big problem in this region. Low-energy binders are in this case very indicated. For an effective use of Mbuji-Mayi raw material for cement and others calcareous binders production, many studies have to be achieved and this one is a starting point.

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