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RESEARCH ARTICLE

CHARACTERIZATION OF LATERITIC SOILS FOR USE IN THE MANUFACTURE OF COMPRESSED EARTH BLOCKS (CEB)

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Abstract

Soil is a widespread natural resource. It comes from the degradation of the mother rock, following the phenomenon of climatic and chemical erosion. Therefore, all soils have very different characteristics depending on their origin [1,2]. Today it is estimated that more than one third of the world's population lives in earthen housing [3]. In view of the advantages offered by the earth material, several developing countries have adopted the raw earth construction in order to face the housing crisis that is intensifying nowadays. Among the advantages of raw earth, we can highlight the low energy required for its implementation, its aesthetic qualities and good thermal inertia, which allows a cool habitat in summer and retains heat in winter. But the problem with earthen constructions is that they suffer from a lack of resistance, systematic cracking due to shrinkage and problems related to their sensitivity to water [4]. From ancient times to the present day, man has sought to avoid the disadvantages of the earth material, using several means of stabilization to improve its performance and its sensitivity to water, which has given rise to several earth products: adobe, adobe, cob, compressed earth block (CEB) and others. Stabilizing the earth is to give it the properties reversible against physical stresses [5], it is currently confirmed that the stabilization of CEB by binders and bitumen improves their mechanical resistance and insensitivity to water [6]. Thus, scientific studies have been conducted on the stabilization of raw earth by mineral binders (cement and lime) for the most part [7] and by fibers (animal, vegetable and synthetic). However, the use of these mineral binders in high proportions may call into question the ecological character of the material [8]. The knowledge of the physical characteristics of lateritic soils is very

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important for their better use in the manufacture of compressed and stabilized earth blocks. Some social strata for the manufacture of CEB use lateritic soils without control of their physical characteristics, which leads to consequences such as progressive crumbling of walls, cracks, poor performance of plasters, and discouragement of the use of the said technology. In this study we intend to compile the most reliable experimental data on the physical properties of natural earth and the mechanical properties of CEB. We will take inventory of the performances determined in previous works by several research teams regarding the characterization and stabilization of lateritic soils to be used in the manufacture of CEB. We will give an overview of the state of knowledge concerning the different properties (physical, mechanical and hygrometric properties). Finally, a literature review will also give some orientations for future scientific research.

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..... **Introduction:-**

The threat of global warming is real and the economic crisis is imminent. The so-called modern materials such as concrete and steel are almost inaccessible for a large part of the population, because of their high costs. The populations close to the forests have opted for wood construction, but this cannot be truly qualified as sustainable as its anarchic use accentuates deforestation and fire rates. Raw earth construction would be an alternative for sustainable development [9]. However, the earth material is very little adopted, perhaps due to a lack of knowledge of its properties or ignorance of improved techniques of manufacturing CEB; inadequate implementation of compressed earth bricks in the buildings constructed, resulting in a limited life span. In developing countries, unbaked earth is often seen as a symbol of poverty and poor quality. Earthen construction is replaced by concrete, sheet metal and breeze block constructions, which are considered modern and durable [10, 11, 12]. This is due to the lack of knowledge of the thermal and hydrometric properties of this material, which guarantees an unparalleled comfort and a highly appreciated aesthetic. Raw earth has been used as a building material for eleven millennia on all continents [13]. After being abandoned and forgotten with the advent of industrial building materials, especially concrete and steel, earthen construction is nowadays the subject of renewed interest in developing countries as well as in industrialized countries following the development of a wide range of production techniques, supported by extensive scientific research. The reason is simple and lies in the advantages that earth material offers in relation to sustainable development building a balance between economic, social and environmental. In view of the abundance and availability of raw earth and the advantages that earth material offers, all populations should join the raw earth construction in order to face the housing crisis that is intensifying day by day. Building with earth requires craftsmen to have knowledge of the material. However, the scientific knowledge of the material is limited, this study is an update of the available knowledge on the physical parameters of natural materials, as well as the hygrometric and mechanical parameters of blocks, 32 years after the appearance of the book of Houben and Gillaud in 1989 [14], it deals mainly with the intrinsic properties of the material. This update is an opportunity to review the current state of knowledge and to highlight the gaps in certain technical data. The high hygroscopicity of the materials also has an impact on the mechanical properties resulting from the interaction between the pore water and the clay fraction. This interaction can lead to swelling or shrinkage [15,16] and can cause the reduction of strength and stiffness. A common way to reduce the adverse effect of water on the mechanical behavior and thus improve the durability of earth materials is to add hydraulic stabilizers such as cement or lime [17], which however increases the environmental impact [18]. Recent research has therefore focused on the development of alternative binders, from cow dung [19] to geo-polymers [20] with lower energy footprints than conventional ones.

Physical characteristics of the materials

Granular composition

The grain size of the soil for earth construction should preferably be within the spindle of the following texture diagram and follow its general shape (Figure 1). The boundaries of the spindle are recommended by CRATerre (International Centre for Earthen Construction, established in 1979). Soils with a texture within the recommended spindle (Figure 2) will in most cases give satisfactory results in terms of strength. The BS1377-2, 1990 standard for geotechnical works, used by Houben in [21], defines a permissible range of grain sizes for raw earth constructions,

while other research works [22], recommend proportions of clay (15-30%), silt (10-30%) and sand (50-75%) for adobe blocks. In general, the clay content should be high enough to ensure acceptable levels of stiffness and strength while the expansive fraction should remain below 50% of the total clay content to avoid cracking. Experience in building construction also indicates that particle size distribution cannot be used as the only parameter to make the choice between earth materials [23,24,25]. However, as Schroeder points out in [26], the current knowledge about grain size curves does not justify the application of such narrow limits, the purpose of the spindles is to provide a recommendation and not to constitute a rigid regulation. These remarks are also made in the state of the art carried out by the TC Rilem "Testing and characterisation of earth-based building materials and elements" [27], one of the chapters of which deals with the characterisation of soils used in the different raw earth construction techniques. The spindles proposed in the literature are only a benchmark and are therefore used with a certain tolerance. There are, in fact, other recommendations on the granularity of soils in the literature that do not always meet with consensus [28].

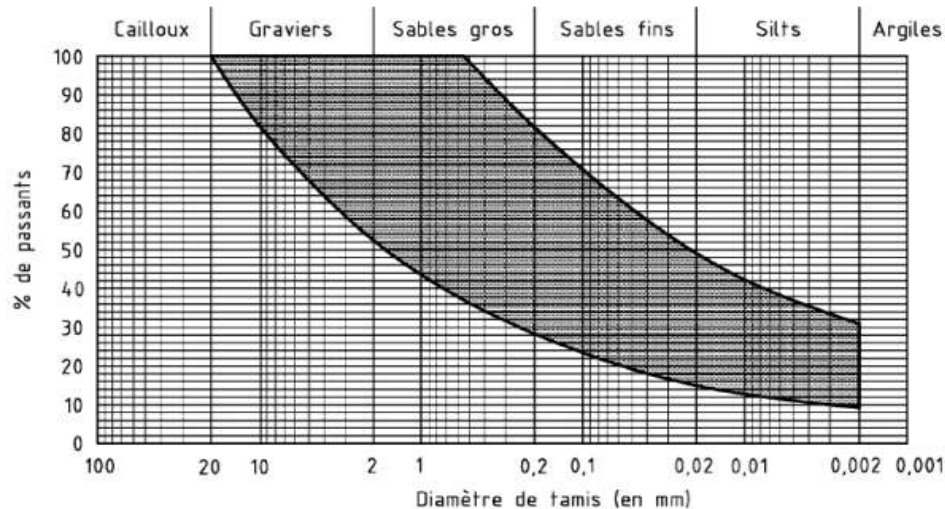


Figure 1:- Soil texture diagram range according to XP P13-901[29].

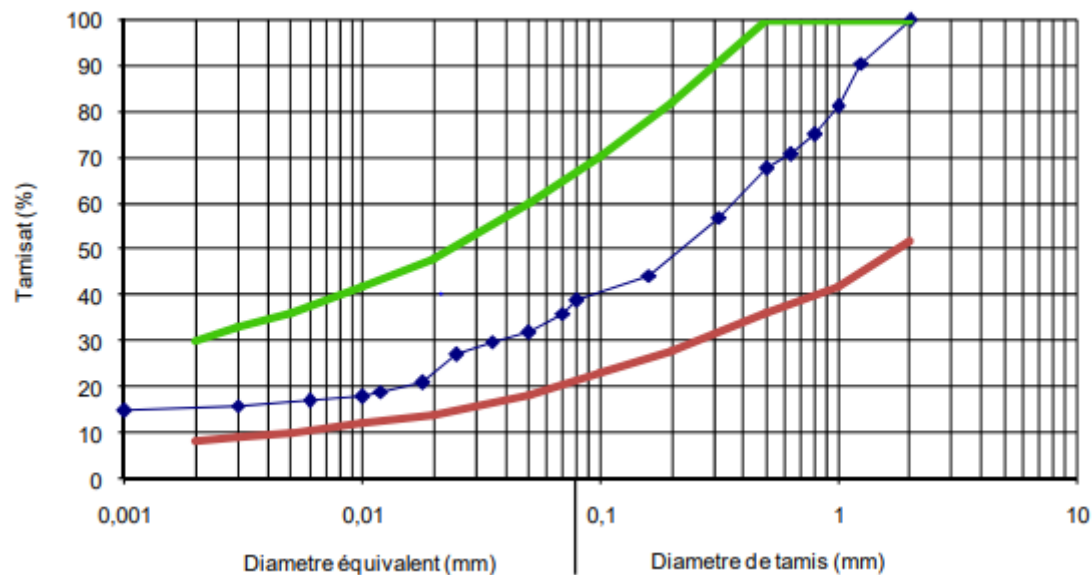


Figure 2:- The grading curve of the soils which is totally within the recommended limits [30].

The particle size analysis and sedimentometry according to the standards show that the samples studied are clay soils or not, if the particle size curve goes out of the recommended range for the manufacture of CEB then it will be necessary to correct these materials by adding others before its use. Figure 3 shows the graphs of the uncorrected and sand-corrected grading curves according to the work of Bokor Youssouf in 2011 [31].

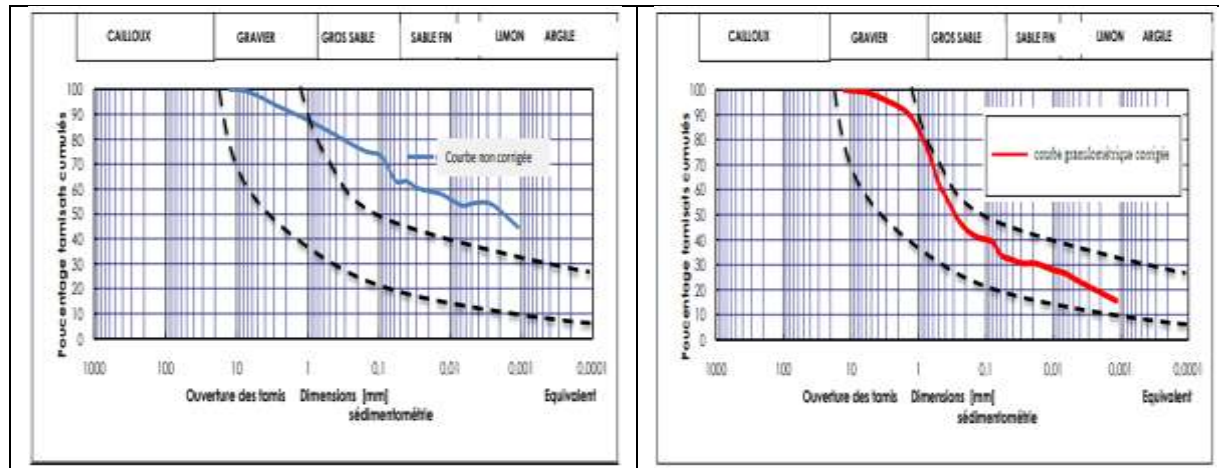


Figure 3:- Graphs of uncorrected and corrected sieve size curves [31].

Consistency Parameters

Consistency parameters (Atterberg limits) are used to analyse the variations in consistency of fine soils as a function of water content [32]. As with granularity, statistical studies have been carried out to define the most suitable Atterberg limits for Compressed Earth Blocks (CEB) and to quickly predict the constructive possibilities of a soil [33]. The tests defined by Casagrande are carried out on soil mortar ($d < 0.4$ mm) according to the procedure of the NF P 94 051 standard [34]. The Atterberg limits are compared to the plasticity diagram (Figure 4) defined by the CEB standards [29,35]. Soils with a plasticity within the spindle give satisfactory results in relation to the CEB.

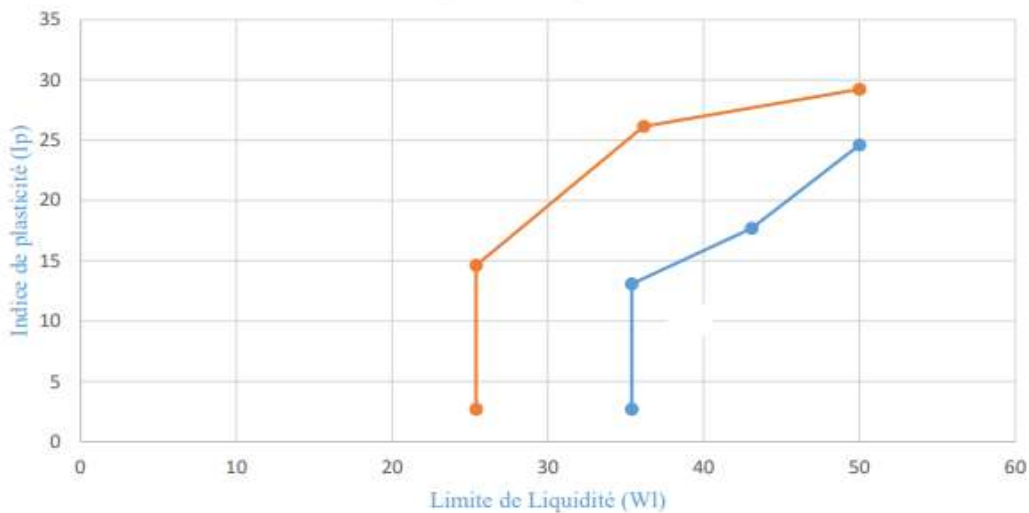


Figure 4:- Boundary spindle of the plasticity diagram [35].

Soils that fall within the recommended plasticity range will in most cases give satisfactory results. However, soils with plasticity outside this range may still give acceptable results, but it is recommended that they be subjected to an additional set of tests after correction. We will comment on the results of the consistency parameters from the work of Oyelami 2016[36] of the ADK and OS samples presented in Tables 1 and 2 respectively.

Table 1:- Consistency parameters of ADK lateritic soils[36].

Samples	Liquid Limit W_L (%)	Plastic Limit W_p (%)	Plasticity Index I_p (%)	Linear shrinkage(%)	AASHTO Classification	USCS Classification
ADK1	32,4	17,1	15,3	1	A-6	SC
ADK2	26,01	12,8	13,21	0,8	A-6	SC
ADK3	55,04	23,9	31,14	0,9	A-7-6	SC
ADK4	37,33	22,2	15,13	1	A-2-6	SM

ADK5	46,2	18	28,2	0,9	A-7-6	SC
ADK6	33,96	16,1	17,86	1,1	A-2-6	SM
ADK7	32,17	19,32	12,85	1	A-6	SC
ADK8	40,17	17,6	22,57	1,1	A-6	SC
ADK9	38,56	21,4	17,16	0,9	A-6	SC
ADK10	31,56	18,17	13,39	0,8	A-6	SC
ADK11	32,1	16,6	15,5	0,9	A-6	SM

Table 2:-Consistency parameters of OS lateritic soils[36].

Samples	Liquid Limit W _L (%)	Plastic Limit W _p (%)	Plasticity Index I _p (%)	Linear Shrinkage(%)	AASHTO Classification	USCS Classification
OS 1A	40,18	13,6	26,58	0,9	A-2-6	SM
OS 1B	41,56	18,2	23,36	1,2	A-7-6	SC
OS 2A	51,82	35,2	16,62	1,1	A-7-5	SM
OS 2B	44,56	32,5	12,06	1	A-2-7	SC
OS 3A	44,94	29,9	15,04	1,1	A-7-6	SM
OS 3b	42,7	30,4	12,3	0,9	A-2-7	SM
OS 4A	51,16	16,6	34,56	1,3	A-7-6	SC
OS 4B	43,92	19,8	24,12	1,2	A-7-6	SC
OS 5A	35,63	17,5	18,13	1,2	A-6	SC
OS 5B	38,6	33,7	4,9	1,1	A-2-4	SC
OS 6A	53,76	29,2	24,56	1,3	A-7-6	SC
OS 6B	47,43	21,9	25,53	1,2	A-2-7	SM
OS 7A	36,26	17,4	18,86	0,9	A-6	SC
OS 7B	40,79	18,1	22,69	1,2	A-7-6	SC

The results in Tables 1 and 2 of the Atterberg limit test show the following consistency ranges of the samples from both localities (ADK and OS): liquid limit (WL) varies between 26.0 and 55.0%, plastic limit (Wp) between 12.8 and 35.2%, while the plasticity index (Ip) varies from 4.9 to 34.56%. The plasticity graph in Figure 5 shows that most of the soils in both locations are inorganic with medium plasticity. In view of the configuration of the points of these materials in the Casagrande chart in Figure 6, these soils are therefore considered suitable for earth construction as it is generally accepted that soils for earth construction fall into the range of inorganic clays of medium plasticity as well as inorganic silts of low and medium compressibility in the Casagrande chart [37].

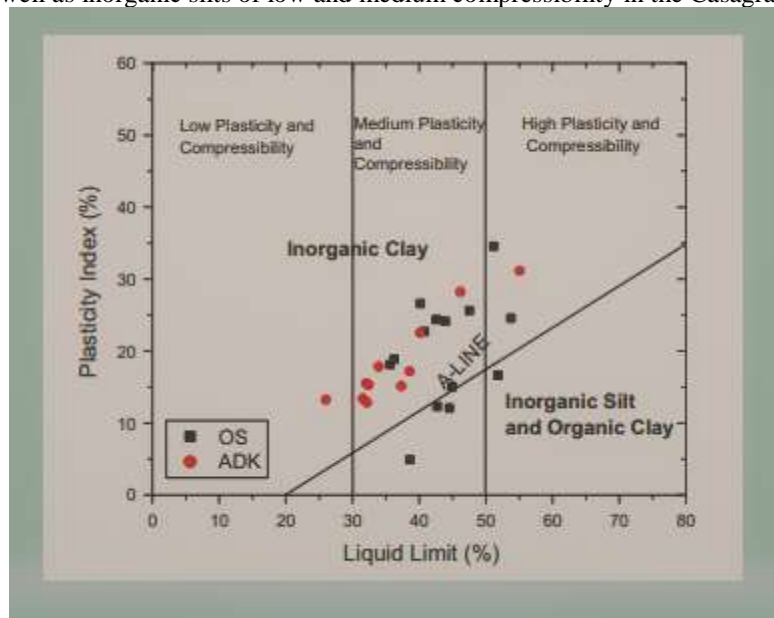


Figure 5:- Plasticity chart of soil samples from ADK and OS [36].

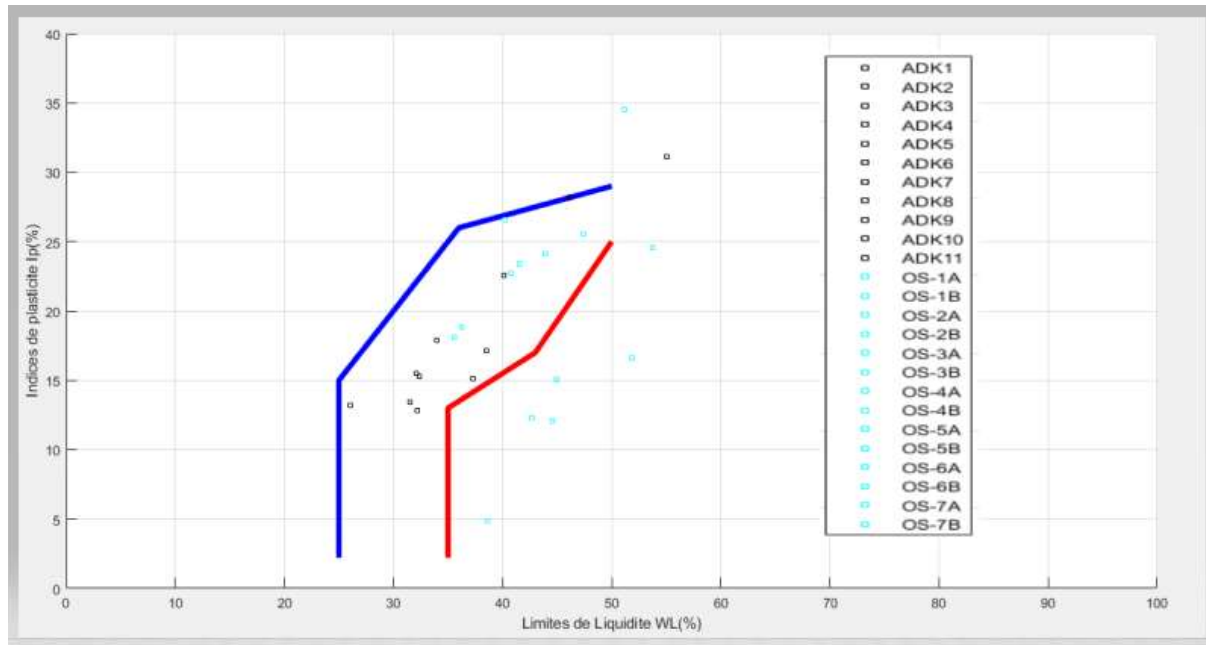


Figure 6:- Position of the points representing the studied materials from ADK and OS in the earth plasticity diagram for CEB [36].

Figure 6 shows the comparison of the plasticity and liquidity index values of the ADK and OS materials with the AFNOR (2001) standards [38], which are intended to help identify soils suitable for earth construction. It can be noted that only some of the ADK and OS materials are located inside the spindle, while the others are located completely outside and on the border. This again underlines the indicative and unnecessary aspect of the spindles, as all materials are from real constructions. The points representing the materials studied that do not fit into the preferred plasticity zone recommended by the standards for the manufacture of CEB, this is due to the high content of fine particles in these materials. It follows that it may be necessary to correct the particle size composition of the materials studied before they are used in the manufacture of blocks. In order to improve the particle size of these alterites, a physical correction by adding sand in various proportions can be carried out for adoption.

Earth Stabilisation

The United Nations Centre for Human Settlements has defined soil stabilisation as the modification of the properties of a soil-water-air system to achieve permanent properties compatible with a particular application [39]. However, stabilisation is a complex problem as many parameters are involved. It is necessary to know: the properties of the soil, the improvements envisaged, the economics of the project, the techniques for applying the soil chosen for the project and the maintenance of the project carried out [40]. The objectives pursued during the stabilisation process are to obtain better mechanical characteristics (increase dry and wet compressive strength), reduce porosity and volume variation or swelling and shrinkage in the presence of water, improve resistance to wind and rain erosion and reduce surface abrasion while waterproofing the brick surface. For this purpose, mechanical, physical and chemical stabilisation processes are reported in the literature [5,41].

Mechanical Densification

Compaction is an operation that is accompanied by a reduction in the volume of voids in a soil [42], thus a higher dry density. For all materials, there is a clear relationship between dry density and mechanical strength. The more compact the material, the higher the strength [43]. The density of a compacted soil depends on several physical variables: the density of the soil particles, the granularity, the water content, the compaction method and the compaction stress. If the soil is too rich in clay, the first materials to be added are sands and gravels. This is because they provide a more evenly distributed grading curve. Shrinkage and swelling will be controlled and a better distribution of porosity will be obtained. The density will also be higher due to a better cohesion between the soil particles. Pozzolans, such as certain volcanic ashes, can also be added to soils containing too much clay [4].

Stabilisation with cement

Cement is a hydraulic binder, i.e. a chemical stabiliser capable of setting in water. It is a very fine grey powder which, when mixed with water, forms a paste that sets and hardens progressively over time. There are various types of cement: pozzolanic cement, which is the oldest and most primitive grade; portland cement, which is very common; and the new high alumina cement. According to Venuat (1980) [44], all standard cements are suitable in principle for soil stabilisation, but preference is given to low-grade cements, as high strength is not required. The literature has shown that chemical stabilisation with cement produces very good results in terms of improved mechanical properties [45,46,47,48,49]. In general, at least 5-6% cement is required to achieve satisfactory results (Figure 7). Compressive strength is still highly dependent on the dosage, with 8% cement often being an economically acceptable upper limit [30]. According to Gooding (1993) [50], the stabilised earth block with 3-12% cement by mass seems to be the most common block. Heathcote (1994) [51], shows that the minimum cement content is 0.75%, above which the strength is independent of the amount of cement used. However, the author's results are not in agreement with those of other researchers who require a value between 5 and 12% to be most suitable. For example Walker (1995) [52], states that blocks with less than 5% cement are often too friable to handle. Later Walker (1996) [53], recognises that the clay content of the soil should be between 5 and 20%, the cement content between 4 and 10% and the soil plasticity index between 2.5 and 30%.

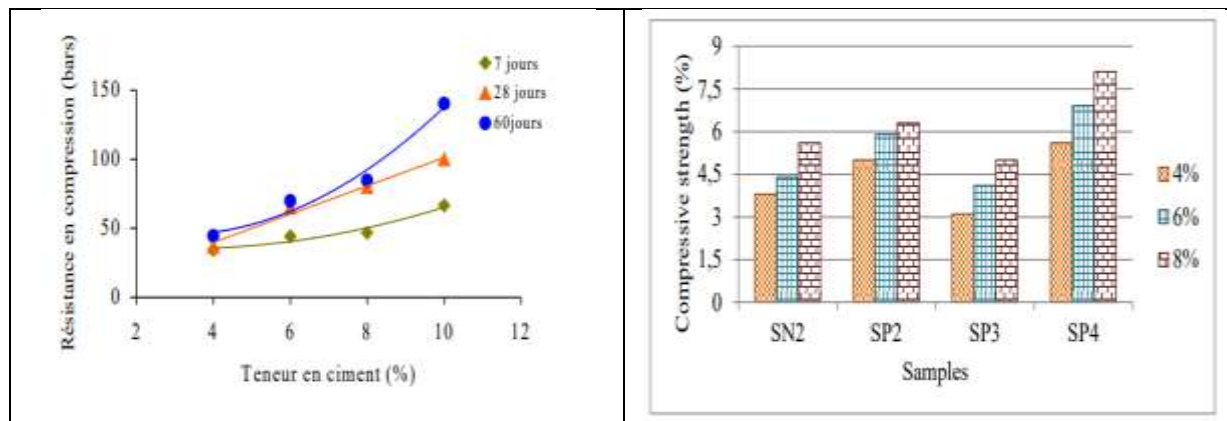


Figure 7:-Variation of mechanical properties as a function of cement content and time [54,55].

Lime stabilisation

Lime is a generally powdery, white material obtained by thermal decomposition of limestone. Chemically, it is a calcium oxide with more or less magnesium oxide, but the usual designation of lime can encompass different chemical states of this product. All types of lime can be used, but air lime is preferred to hydraulic lime. Lime is especially recommended for soils with a clay fraction of 20% and soils with PI (Plasticity Index) > 17 and LL (Liquid Limit) > 40 [30]. Slaked lime is much more recommended than quicklime, as the latter has two major disadvantages: it is difficult to store away from moisture before use and it is difficult to handle when mixing. Le Roux (1987) [56] proved that for kaolinite-rich soils, the strength (from 2 to 90 days) increases with the lime content, but that for illite-rich soils, an optimum of 5% lime is characterised in the medium and long term. Numerous studies have shown that the simple compressive and flexural strength of CEB increases with the stabiliser content from 8% to 15% and the time to crush [30,31,57,58]. For example, the work of Sore (2013) [59], revealed an improvement in the intrinsic properties of CEB by slaked lime, the best physical and mechanical properties were obtained with CEB samples containing 15% slaked lime (Figure 8).

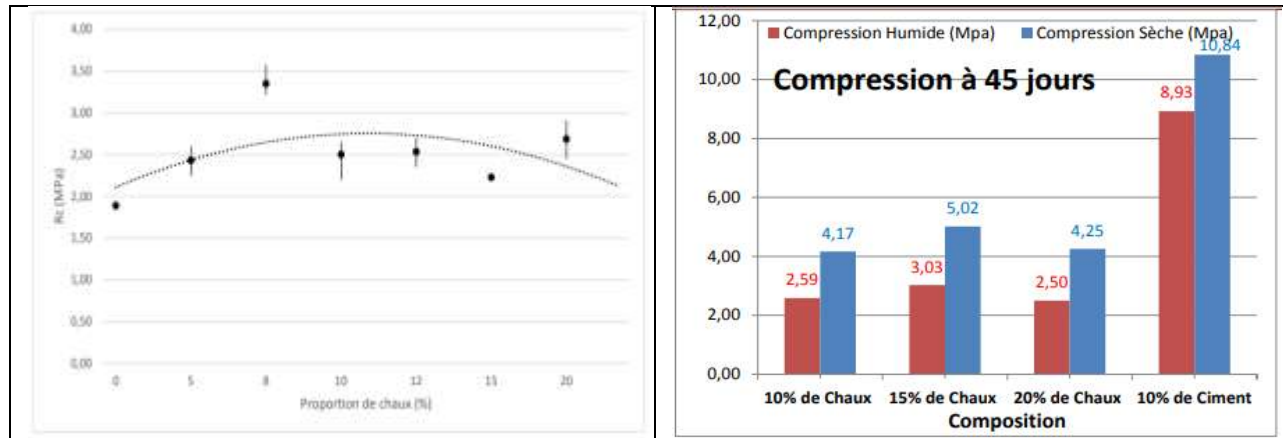


Figure 8:- Variation of mechanical properties as a function of lime content [59,60].

Stabilisation with natural fibres

The addition of natural fibres to clay is a stabilisation method commonly used in the manufacture of adobes and other earth products and has been used for thousands of years [61,62]. The role of the fibres is manifold, on the one hand they increase the tensile strength and consequently the flexibility of the material. The use of local natural fibres is more advantageous for the population, given its abundance, low cost, low energy consumption and reduced environmental impact [63,64,65,66,67]. With the evolution of technology, studies on CEB have shown that the addition of natural fibres reduces the size of cracks caused by shrinkage and improves durability and tensile strength [68,69,70]. For example, the results of the work of Millogo 2014[71] proved that the presence of hibiscus cannabinus fibres improved the physical and mechanical characteristics of blocks. A significant effect was observed with the case of 30mm fibre length than that of 60mm length (Figure 9). Sallehan and Yaacob (2011) found that the addition of 3% palm fibre improved the compressive strength of fibre bricks [72]. In his study, Namango found, that within certain limits, there is a considerable increase in dry compressive and flexural strength with increasing sisal fibre, cassava powder and cement content, and that outside these limit values, the presence of sisal fibre has an adverse effect on the strength of the compressed earth block [73].

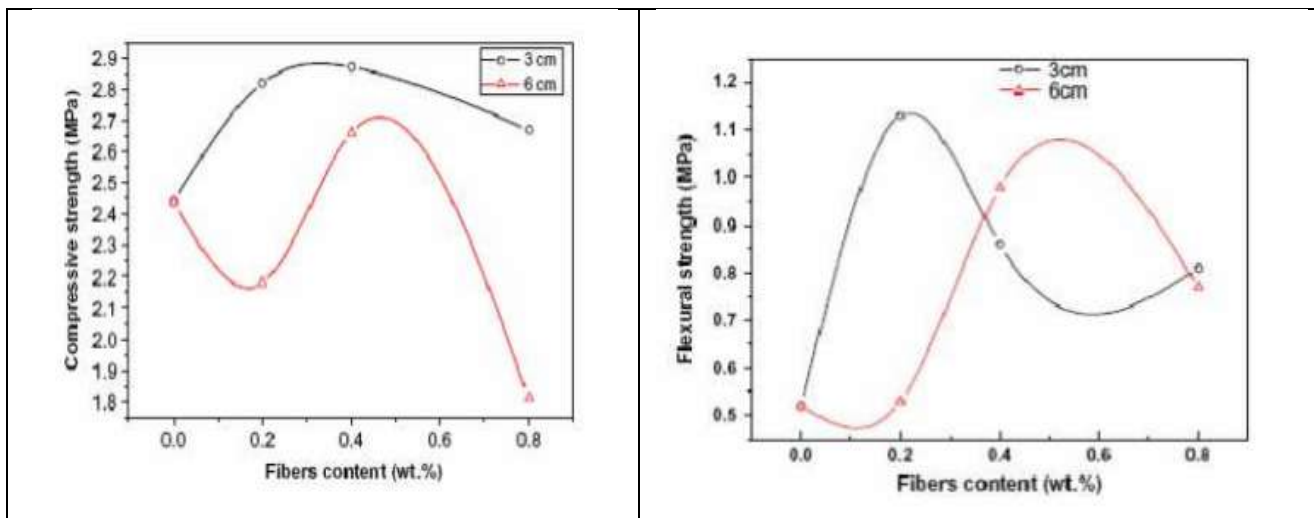


Figure 9:- Compressive and flexural strength curves as a function of fiber content and length of fiber [71]

Abrasion resistance

The abrasion resistance of green earth bricks is carried out according to the experimental standards NF XP 13-901 [74] and NF EN 530 (2010) [75]. The objective is to subject the brick to friction using a 25 mm wide metal brush. The rate of return movement on this face is 1 return movement per second for one minute, i.e. 60 return movements. From this test, the abrasion coefficient of the brick is deduced, which represents the loss of material due to the brushing of the brick on the abrasion surface. The experimental standard indicates basic coefficients that allow a raw

clay brick to be classified according to its resistance to abrasion. The higher the abrasion coefficient of the brick, the better the resistance of the clay brick. The increase in the dry density of the bricks by compression is greater than the material significantly improves the abrasion coefficient of the brick. This improvement allows the brick to be classified as CEB 40 or 60 according to the specifics of the Mayotte experimental standard. From the work of Nshimiyimana [48], abrasion coefficients of more than 7 cm²/g are obtained, which classifies the bricks in the very good resistance class, i.e. CEB60. According to the work of Flament (2015) [76], it was noticed that the increase in the quantity of material allows a better cohesion of the clay nodules. During the passage of the brush, these nodules, more solid, resist abrasion more easily. Similarly, KAMGA (2018) [77] demonstrated that the values of mass loss by abrasion vary from 3.85% to 10.32% for stabilisation with a sand/soil ratio of 1/3, 1/2 and 2/3 for reddish plastic clays. Similarly, for the less plastic clays of purplish red colour, these values vary from 23.83% to 25.36%, for the sand/soil ratio of 1/3, 1/2 and 2/3. It is noted that the first category is resistant to abrasion, while the second category is not, as the values are above the admissible value of 5% [78].

Hygroscopic properties

Water content

The water content of the soil is an important parameter if one is interested in the mechanical and thermal properties of the material, so it is important to know the variation in water content of the soil in the ambient humidity. The water content of the soil at equilibrium is higher if the relative humidity and porosity are also high. Under normal conditions of temperature and pressure, with a relative humidity of less than 70%, the percentage of water content in earth walls generally varies between 0.5 and 5%. It can be higher especially in the presence of swelling clays and aggregates containing micropores and microrugosity [79,80, 81]. For example, in studies by Eckermann in 2007 [82], it was found that soil generally has a higher water vapour retention capacity than concrete or gypsum. This high water retention capacity is related to the porous and microporous structure of the soil, but also to the physicochemical properties between clay and water. Swelling clays have the highest affinity with water, due to their large surface area and high cation exchange capacity. According to Flament in 2015 [76], mass stabilisation of CEBs is achieved after 20 days of drying at 20°C and 50% relative humidity (Figure 10).

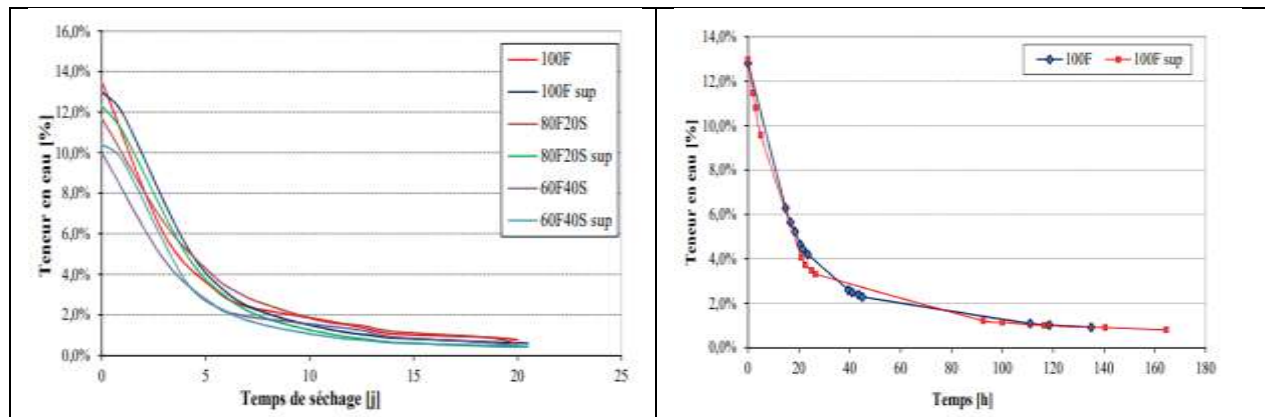


Figure 10:- Variation of water content of CEB as a function of drying time[76].

Shrinkage and swelling

During the drying phase, the soil undergoes volumetric shrinkage or shrinkage, due to water shrinkage: the clay platelets shrink due to the increase in capillary forces caused by the loss of water when the suction increases. This shrinkage can under certain circumstances cause cracks which must be controlled. Conversely, when dry soil is loaded with moisture, it expands due to the release of capillary pressure, resulting in the swelling of clays with a high water holding capacity. For practical reasons, it is useful for builders to know the shrinkage values of the soil from its condition to its use as a building material. The magnitude of shrinkage is limited if the water content used in the material is low as well as if the clay content is low. The addition of plant fibres to the soil is an effective way to avoid or limit shrinkage. The presence of salts in the soil can also modify the extent of shrinkage [83,84]. The mechanisms involved are complex and depend on the nature of the ions present. The shrinkage of the soil from its raw state to its use as a construction material can vary between 1 and 20%. For adobe, the percentage of shrinkage is between 1 and 3% [80,85,86,87].

Water Absorption

Water absorption is a function of the age of the bricks and the clay content as well as the stabiliser content (cement, lime and fibre), it increases with increasing clay content and decreasing cement content (Figure 11). It has a strong influence on the strength and durability of CEB. This absorption and desorption property is very important for the interior comfort of the building, as it allows hygrothermal regulation, which keeps the humidity level relatively stable inside. The water absorption rate should not be too high to avoid swelling of the clay fraction or loss of cohesion of the CEB, therefore sand can be added to the mix. The addition of fibres increases the water absorption. Thus, for cement-stabilised CEB, the absorption is around 10%, for lime-stabilised blocks it is around 12% and for fibre-stabilised blocks it is around 13% [10]. The addition of cement has a beneficial effect on the water absorption of the stabilised earth block. Figure 11 shows the variation of the water absorption rate with time at different stabiliser contents. The results of Meukam's study in 2004 [54], show that, for a cement content varying from 4% to 8%, the absorption rate decreases sharply. For all exposure times, this water absorption rate is practically stable when the cement content exceeds 8%. Similarly, the results of Taallah in 2014 [30], show for all fibre contents used, when the lime content increases from 8% to 10% there is a small decrease in water absorption, whereas after 10% there is a significant increase in water absorption.

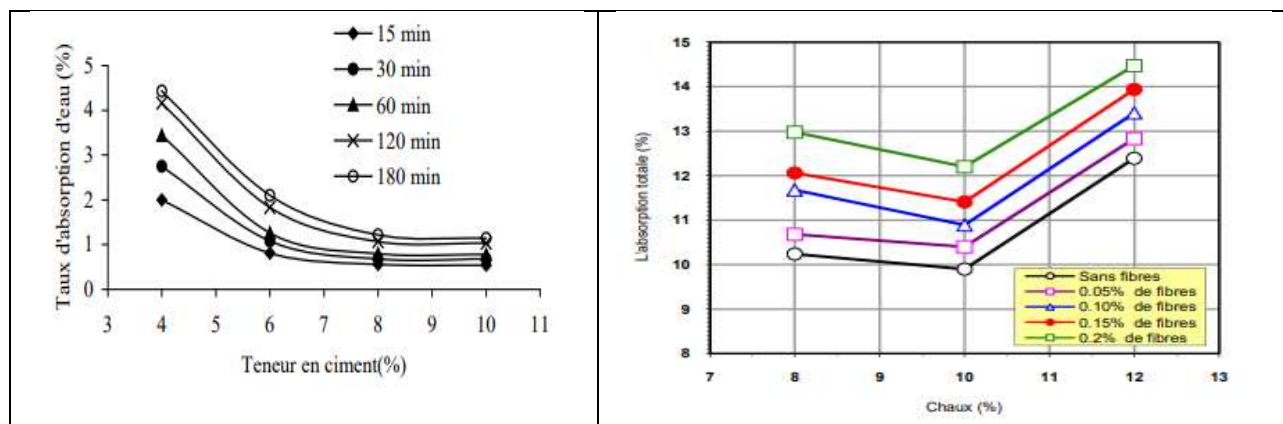


Figure 11:- Variation of the water absorption rate over time of CEB stabilized in cement, lime and fiber [30,54].

Conclusion:-

The aim of this study was to identify and analyse some of the available studies 32 years after the appearance of the book by Houben and Gillaud in 1989 on the characterisation and stabilisation of lateritic soils for the purpose of making CEBs. From this overview, there is little reliable experimental data on the properties of raw earth for construction. These data are very fragmented, as they often relate to one type of soil and focus on only a few properties. The main post-stabilisation properties of raw earth that have been uncovered are summarised in this literature review.

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