Characterisation of laterite stone as building material in Burkina Faso: state of the art of the on-going research and its perspectives

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INTRODUCTION
The rapid rate of urbanization undergoing in developing countries and the increasing pressures on what are often limited resources ask for sustainable interventions while these built environments are being created. This paper summarises the first results of a study that is investigating whether or not the laterite dimension stone can be a possible material to be use (when available) for housing, in rural as well as in urban areas. Laterite dimension stones have been used for building construction in tropical and subtropical regions of the world where they are readily available and economical compared to other natural stones. Although the definition of “laterite” is still quite controversial, it can be assumed that laterites are the products of intensive and long lasting tropical rock weathering which is intensified by high rainfall and elevated temperatures, and hence it is not possible to commonly class them (as igneous, sedimentary or metamorphic rock). Laterite can be treated as a “weak rock” for building purposes and, when moist, it can be easily cut into regular-sized blocks. However, after exposure to atmosphere, laterite blocks show a hardening behaviour which is thought to be due to the content and dehydration of iron oxides and arrangement of components.

RESEARCH GOALS AND INVESTIGATION SITES
The research focus on the definition of physic-mechanical parameters of some examples of laterite dimension stones (LDS) which can be found in Burkina Faso, in order to define the required guidelines for (a) characterisation procedure; (b) normalisation process. An investigation carried out in 2006 listed (not exhaustively) more than sixties LDS quarries, homogeneously distributed across the Country. This figure helps to understand why a full characterisation could not be feasible under this research framework, while it is rather necessary to state procedures and normalisation parameters to (a) regulate the economic sector; (b) promote the enhancement of quarrying systems, fostering the quality of the product and pursuing its full dissemination. This paper will describe the results obtained for the Dano site, which has been more extensively studied at this research stage, even if some comparisons could be carried out for others sites.

The geological map in the area of Houndé (1/200,000) indicates the Lower and Middle Precambrian age strata (called “Precambrian Birrimian” for West Africa), consisting of acid rocks (granites, migmatites and gneiss - earlier Birrimian) and the subsequent Birrimian series with mafic volcanic, pyroclastic and volcano-sedimentary rocks. Lateritic structures are visible through the landscape as plateaux slightly tilted to the east. Laterites cover a bedrock identified as schistosed andesites, whose schistosity follows the Birrimian directions NNE-SSW and N60 ° to N80 ° E as confirmed by intercalated quartz veins. Faults, even if difficult to be detected, are aligned on a direction N 120 ° E. A geological survey, carried out in July 2010, identified outcrops of bedrock and allowed the examination of exposed vertical faces. Moreover, samples for laboratory testing have been collected. The mineralogical study of such samples will allow establishing a relationship between the parental rock and the resulting laterite.
CARRIED OUT TESTS
More than 150 tests have been performed through this extensive characterisation campaign. Nevertheless, some results indicated a necessary refinement for certain parameters and therefore consistent data are still to be consolidated, as it will be discussed in conclusions.

1. Physical properties
Specific gravity, natural water content, dry unit weight, void ratio and porosity have been obtained through laboratory tests. Dry unit weight has been obtained via liquid immersion measurements after sealing the oven-dried specimen with paraffin. Specific gravity has been measured via pycnometer. Others parameters have been calculated according standard soil mechanics procedures. Obtained specific gravity of 31.9 kN/m$^3$ is higher than average minerals value (26.5 kN/m$^3$), thus confirming the predictable high rate of heavy iron oxides.

9 samples sized 15 x 15 x 15 cm have been used for determining the water absorption for the investigated rock. The goal of this test was to assess the variation in weight of dry specimens (oven-dried for 48 hrs at 150°) when immersed in water. The carried out tests allowed to follow this development during test-time and to plot the absorption Hp vs. time. The saturation process follows a logarithmic law with satisfactory fitting ratio. It is worth to note that the saturation occurs after 48 hours at last, whereas some samples can be considered saturated after 24 hours only. After 10 minutes, about 33% of final saturation value is reached, whereas after 70 minutes the saturation is 55 – 65% of final value.

Compression tests
59 tests have been performed for determining the Uniaxial Compressive Strength (UCS), varying specimen size and proportion (from exploitation block dimension, i.e. 40 x 20 x 15 cm, to cubic samples 10 x 10 x 10 cm), water contents (natural water content, oven – drying at 105° for 24 hours, immersion in water for the water saturated conditions), and cyclical wetting and drying in order to assess possible variation in their final strength. Tests have been carried out with conventional hydraulic servo-assisted press with full scale 160 kN, and during some trials the axial deformation has been recorded with a 1/100 mm sensitivity mechanical transducer. An effort has been made to measure the horizontal displacement, but no valuable result has been obtained.

Obtained UCS are comprised within 1.5 and 5 MPa, values that are in agreement with published results (UCS in a range of 0.5 – 3 MPa) for Indians laterites, and comparable with other investigated building stones: Hınıs ignimbrites, which presents (for 3 out of 4 rock types tested) a UCS in the range of 1.6 – 2.8 MPa; Southern Anatolian Tuff, with UCS of 6.2 MPa; Quaternary caliche deposits in southern Turkey (range 2.03–10.41 MPa). Even if classifiable as “weak rock”, the LDS under study confirms therefore its potentialities for building applications.

As far as the size effects are concerned, it is useful to observe that bigger blocs result in lower UCS. This result was predictable and confirmed by other available literature data. This observation is of high importance since implies that the actual size of LDS used for masonry applications has a definitive impact on the available rock strength. Therefore, for the definition of normalisation codes, it is necessary to clarify test conditions and specimen dimensions further to UCS alone.

Considering the presence of water and its effects, it can be observed that dry samples show an UCS that is twofold in comparison with wet samples, whereas there is no statistical difference between saturated samples and specimens at natural moisture conditions.
2. Flexural tests
9 tests have been carried out for determining the flexural strength for panel-shaped specimen. Laterite samples were sized 40 x 20 x 5 cm, solicited with a centred – vertical load and laying on two base points. Vertical displacements were measured by means of a 1/100 mm sensitivity mechanical transducer. Results for moist samples are in the range of 0.5 to 1.8 MPa, with an average value of 1.15 MPa, which represents about 30% of UCS obtained under the same conditions.

3. Young’s Modulus
During several compression tests on 20 x 20 x 15 cm blocs, axial deformation has been measured with a 1/100 mm sensitivity mechanical transducer. Stress-strain curves have been plotted and numerical linear regression for the initial stretch of the curves has been performed for obtaining the Young’s Modulus $E$. A total of 15 results have then been recorded. The average obtained value is about 0.25 – 0.28 GPa, well below usual values for rocks. Comparisons can be made with Indian laterites, which flexural modulus of elasticity for wet samples varies from 0.25 to 0.47 GPa, while for dry samples the range is 0.4 – 0.6 GPa. Tests on Quaternary caliche deposits in southern Turkey gave a range of 0.16–1.40 GPa for Young’s modulus. The classification proposed by Deere and Miller takes into account more than one measurable property at a time, since a modulus ratio, $E_t/\sigma_{ci}$, has been introduced and each intact rock type has been assigned to a specific zone in the region of $\sigma_{ci}$ and $E_t$. For the laterite rock under investigation, calculated modulus ratios vary from 40 to 70.
A modulus ratio of 50 corresponds to a minimum failure strain of 2%. Very weak rocks and dense/compacted soils often show failure strains of the order of 2%. Therefore, the modulus ratio of 50 has been proposed in as the lower limiting value for rocks, and Dano laterites still fall into such class. A calculation of the Young’s modulus has been carried out back-analysing records from flexural tests (displacement and applied force). Although some results are believed to over-estimate the actual Young’s modulus (giving results up to 3.5 GPa), 5 out of 9 tests gave results comparable with above mentioned findings, with an average value of about 0.6 GPa.

a. Pendulum hammer rebound
The rebound number for a total of 18 samples sized 20 x 20 x 15 cm has been measured using a pendulum hammer. Pendulum hammer was chosen instead of the more commonly used Schmidt rebound hammer, as rebound hammer would have caused failure of the soft laterite during the test. Moist samples (6), dry samples (6) and saturated samples (6) have been utilised for the test. Readings were noted at 7 points for each sample face, for a total of 252 readings for each water content class. Extensive literature exists on the correlation between Schmidt hammer rebound and mechanical parameters of intact rock. Unfortunately, the use of pendulum hammer for weak rocks has not been thoroughly investigated in a similar way; therefore extensions of empirical correlations obtained for Schmidt hammer (L-type or N-type) might be misleading. Furthermore, the utilisation of pendulum hammer proved to be slightly unreliable because of its working mechanism, which is influenced by environmental conditions and operator approach.
An effort has been made by extracting some correlations proposed for UCS ranges compatible with the investigated LDS. Existing correlations overestimate laterite mechanical parameters, therefore are considered not suitable for pendulum hammer results on weak rocks. However, utilising minimum values for hammer rebound with the empirical correlation $UCS = 0.4 Hr -3.6$, a satisfactory prediction has been obtained. Young’s modules are overestimated with a factor of 10 to 30. This is due to extremely low values obtained for LDS.
b. **Thermal tests**

Thermal tests have been carried out on wet, dry, and treated specimens. When compared with other building materials, investigated LDS shows appreciable characteristics. It is to be noted the detrimental effect of water, which lowers as expected the thermal performance of the material. Empirical correlations between physical-mechanical characteristics and thermal parameters have been proposed in literature, but obtained results are not reliable. It is to be concluded that physical-mechanical characteristics of the investigated LDS are out of the range of validity of previous experimental campaigns.

**CONCLUSIONS AND PERSPECTIVES**

Laterite rocks exploitation can support the demand of quality building materials in a sustainable way: economic, for the final cost of construction can be reduced with local material utilisation; ecologic, for the reduction of nuisances and pollution related to the cement and steel production, as well as for the reduction in energetic costs due to better thermal insulation performances; and social, considering that small scale exploitation feeds local economy.

This paper presented results from the first stage of an extensive study currently undergoing at the 2iE with its academic partners on the characterisation of laterite dimensional stones (LDS). The investigated laterite can be classified as weak rock, with low to very low UCS and extremely low Young’s modulus; tensile strength is on the contrary higher than expected. If compared with Indian Standards Specification for laterite stone block for masonry, Dano LDS satisfies the minimal indications except for some sample conditions (big sizes, saturated) where UCS is slightly under the required minimum. Importance of size indications in standard normalisation documents has been pointed out. Empirical correlations available in literature between mechanical and physical characteristics are proved to be not suitable for the investigated LDS, since actual UCS, porosity, E are often out of proposed ranges.

Future developments of the research will involve the following aspects: (a) mineralogical analysis (currently undergoing) for mineral components identification; (b) physical-mechanical parameters refinement with more sophisticated laboratory equipment (under procurement); (c) analysis and quantification of hardening process of laterite after air exposure; (d) extension of the investigation methodology to other two already identified LDS quarries. The final goal of the research is to define a normalisation document to be extended to laterite-rich countries and to give guidance for quality tests on dimensional stones, whose importance is basilar in sustaining, fostering and valorising the exploitation of locally available stones.