Improvement of water resistance and thermal comfort of earth renders by cow dung: an ancestral practice of Burkina Faso

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Abstract: The main objective of this study was to improve some properties (physical, mechanical, hydric and thermal) of earth renders amended by cow dung, as such amendment is an ancestral practice in Burkina Faso. For this purpose, raw clayey material from Kôdeni (in western Burkina Faso), mainly composed of kaolinite (62 wt.%), quartz (31 wt.%) and goethite (2 wt.%) and having adequate geotechnical properties was used to elaborate earth renders reinforced with up to 6 wt.% of cow dung. The cow dung studied was mainly made up of small vegetable fibres, clayey minerals and quartz consumed by cows. Cow dung incorporation limits the spread of cracks and hardens the material thanks to the good adhesion of cow dung to the clayey matrix, which is linked to the rough surface of fibres contained in cow dung. The presence of cow dung in an earth render influences its mineralogy through the formation of insoluble amine silicate ($Si(OH)_4 . 4NH_3$). This compound is formed during the reaction between fermented cow dung with mainly fine crushed quartz and feebly kaolinite in basic medium. The molecule formed links isolated raw material particles through free electronic doublets on the oxygen atoms and especially on the nitrogen atoms. The consequence of this effect is an improvement of the microstructural, physical and mechanical properties of earth renders. In particular, their thermal conductivity is reduced as the fibres present in the composite materials are rich in cellulose (molecule with thermally insulating properties), and their resistance to abrasion and to water is good. The earth renders elaborated in this way help to provide water resistant housing with good thermal comfort.

Keywords: Earth renders; Cow dung; Insoluble amine silicate; Microstructural, physical and mechanical properties; Thermal comfort; Water resistant.

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Highlights

Cow dung addition to earth renders is an ancestral practice in Burkina Faso

Cow dung additions to soil induce the formation of insoluble amine silicate

Amine silicate improves the physical and mechanical properties of earth renders

Earth renders containing cow dung are resistant to water erosion

Earth renders containing cow dung have low thermal conductivity

1. Introduction

In Burkina Faso as in most developing countries, traditional houses are still built using vernacular construction materials such as unfired earth. Considering that modern construction materials like cement and lime are not accessible to the majority of those countries' populations, earth renders are commonly used to protect the earthen walls. Earth rendering has low resistance to weathering and is easily eroded by rain. Therefore, it has to be repaired after each rainy season. Scientific research has mainly addressed this problem by using agricultural by-products to improve the physical and mechanical properties of the materials and to increase their resistance to weathering [1-6]. Cow dung is one such by-product and has been used by populations in developing countries to stabilize earthen renders against water erosion. The cow dung is applied to the outside wall and seems to present no health hazard to the population and, when the earth render dries, no smell is noticed. Empirical experience considered as ancestral practice has shown that cow dung has a real potential in the development of cheap, water-resistant earth renders. A few authors, e.g. Ngowi et al. [7], Vilane et al. [8] and Millogo et al. [9] have reported the use of cow dung as a stabilizer for adobes and these studies highlight an improvement in the physical and mechanical properties of adobes where this addition is made.

To the best of our knowledge, the scientific literature on the stabilization of earth renders by cow dung is scarce and very few scientific works have concerned the formation of insoluble amine silicate when cow dung is incorporated into clay materials [9], even though it is important to know its effect on the physical and mechanical properties of earth renders. Also, the impact of cow dung on the thermal properties of clayey materials has not been investigated. This parameter is very important for earth rendering in wet climates, such as tropical and sub-tropical ones.

The present work deals with the influence of up 6 wt.% of cow dung on the physical and mechanical properties of earth renders manufactured with clayey soil from Kôdéni (western Burkina Faso). The effect of cow dung additions on the microstructural properties of earth renders is highlighted and attention is paid to the effect of cow dung additions on the erosion resistance, the resistance to abrasion and the thermal conductivity of earth rendering.

2. Materials and procedures

2.1. Raw materials and manufacture of earth renders

The earth renders were made using grey clay soil from Kôdeni (11°10' N, 04°17' W), a locality in western Burkina Faso. The dried cow dung (unfermented) was collected from farms around Ouagadougou, the capital of Burkina Faso.

The clayey soil was dried at 105 °C and crushed in an agate mortar to obtain particles with sizes < 5 mm and cow dung was dried in the ambient air (temperature of 33±5°C and average humidity of 32%) and crushed. The powder obtained by grinding cow dung always contained fibres of various sizes, with a maximum length of 3 cm. Four different amounts of dried cow dung powder (0, 2, 4 and 6 wt.% of the mixture) were mixed with dried raw clay powder. In contrast to the scientific approach, the amount of cow dung used in the preparation of earth renders is intuitive in the rural world. During manufacturing of earth rendering mortars, farmers stop adding cow dung when suitable plasticity of the soil - cow dung - water mixture is observed.

The water content used for this study was determined using Equation 1:

$$w\ (\%) = (w_L + w_P)/2 \qquad (1)$$

where w_L and w_P are the liquid and plastic limits, respectively, of the raw material.

The amount of water calculated above gave a suitable consistency for earth rendering mortars made with clayey materials mixed with cow dung. The pastes obtained were homogenized for 15 min and then kept for 72 h in hermetically sealed plastic containers in a room at controlled temperature (25 °C) to permit cow dung fermentation. The homogeneous pastes were put into 20x20x2 cm^3 moulds in two layers as follows. The mould was half filled with paste and then manually shocked 20 times. The same operation was repeated after addition of the other half of the paste. The prismatic specimens used for some physical tests (linear shrinkage, compressive and flexural strengths) were elaborated in the same way as the earth plaster specimens (20x20x2 cm^3). After demoulding, the earth rendering mortars were kept at room temperature (30 ± 7°C with average humidity of 32 ± 10%) for 90 days [10]. During the cow dung fermentation procedure, until the mortars were dry, there was a smell similar to that of urine. On the other hand, after the manufacturing and drying of the specimen, any annoying odour disappeared. The compositions of earth rendering mortars are given in Table 1.

Table 1: Earth rendering mortars compositions

Code	Earth rendering mortar description	Clay (g)	Cow dung (g)	Water (mL)
RM	Raw earth rendering mortar	1500	0	495
M-CD2	Earth rendering mortar + 2 wt.% cow dung	1470	30	485.1
M-CD4	Earth rendering mortar + 4 wt.% cow dung	1440	60	475.2
M-CD6	Earth rendering mortar + 6 wt.% cow dung	1410	90	465.3

2.2. Procedures.

2.2.1. Physical, chemical and mineralogical characterization

The granulometric distribution of the clay soil was analysed by coupling two techniques according to NF P 94-056 (coarser fraction (> 80 µm) [11]) and NF P 94-057 (fine fraction (≤ 80 µm) [12]).

The Atterberg limits of the soils were determined according to standard NF P 94-051 [13] and the methylene blue value was evaluated according to standard NF P 94-068 [14].

The chemical composition of the raw material was determined using the Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) technique on the powdered sample obtained after the raw material had been crushed to particle sizes of less than 80µm.

The sample, crushed and sieved to a particle size of less than 80 µm, was analysed by X-Ray Diffraction (XRD) and Differential Scanning Calorimetry (DSC) coupled with Thermal Gravimetric Analysis (TGA). XRD was performed using a Kα (λ = 1.789 Å) cobalt anticathode. The mineralogical composition of the raw sample was obtained using XRD analysis coupled with the results of the chemical analyses. For a chemical element ‘‘a”, the following equation 2 [15] was used to calculate the amount T (a) of oxide (wt.%).

$$T(a) = \sum M_i P_i(a) \qquad (2)$$

where M_i is the amount (in wt.%) of mineral i in the material under study; Pi (a) is the proportion of element a in the mineral i.

The DSC coupled to TGA analysis was performed on crushed samples heated to 1000°C at a rate of 10 °C/min using a Netzsch SATA 449 F3 Jupiter apparatus device. The Infra-Red (IR) spectra were obtained using a Perkin Elmer UATR1 Frontier FT-IR spectrometer (4000–500 cm^{-1}). SEM observations were carried out on cow dung using a JEOL 6380 LV equipped with a backscattered electron (BSE) detector. It was coupled with a Brüker X Flash 6/30 detector to perform energy dispersive spectroscopy (EDS).

2.2.2. Physical, thermal and mechanical characterization of earth rendering mortars

The linear shrinkages (in %) of the earth rendering mortars were obtained from the difference between the initial and final lengths measured before and after drying on the three prismatic specimens ($40 \times 40 \times 160$ mm^3) according to the German standard [16].

The apparent density was measured according to standard EN 1015-10 [17] on the same prismatic samples by the hydrostatic method.

Accessible porosity was measured using an AutoPore IV 9500 V1.10 mercury porosimeter. It was obtained on earth rendering mortar samples according to the procedure used by Grilo et al. [18].

The pH of earth rendering mortar samples was measured using the protocol adopted by Millogo et al. [19]. This pH measurement required some preparation: a 10 g sample of finely ground earth rendering mortar (diameter less than 80 µm) was dissolved in 40 mL of distilled water. The resulting mixture was homogenized with a magnetic stirrer for 2 hours. A Hanna Instruments pH meter was used to perform the various measurements.

The water absorption tests by capillarity of the earth rendering mortar samples were carried out on prismatic specimens ($40 \times 40 \times 160$ mm^3) after drying at 105 °C for 24 h according to EN 15801 CEN 2009 standard [20, 21]. This test consisted of measuring the mass increase of the prismatic specimen placed in a beaker with a water level 5 mm above the underside of the specimen. In practice, this condition was achieved by placing the samples on a bed of gravel and immersing them to a depth of about 5 mm. The mass of the tested sample was then measured at 1, 4, 9, 16, 36, 49 and 64 minutes. The mass of water absorbed per unit of water-exposed surface (in kg/m^2) was plotted versus the square root of time (in s$^{1/2}$) for each defined time in order to determine the absorption coefficient. This parameter is the slope of the linear regression line. The coefficient of linear regression (R^2) was also evaluated. In order to avoid disintegration of the tested samples, the bottom was covered with filter paper.

The spray test used to evaluate the resistance of earth renders to rainfall erosion consisted of spraying water in the form of a rain droplets at a pressure of 2 bars and at a constant flow rate of 5 L/min for 10 minutes on earth renders arranged on a plane inclined at an angle of 30° to the vertical [22, 23].

Mass loss of the earth renders (C_E) was estimated as a percentage from Equation 3:

$$C_E(\%) = \frac{M_0 - M_S}{M_0} \times 100 \qquad (3)$$

with: M_0 the mass of the earth render and M_S the mass of the degraded earth render after drying.

The thermal conductivity (λ) of earth renders was measured using a Neotim hot wire probe associated with a Neotim FP2C power supply and acquisition unit. The probe was placed between two samples of earth renders to ensure close contact between the surfaces of the sample and the probe [24].

Abrasion resistance was assessed on the earth renders by brushing with a wire brush loaded with a constant mass of 3 kg as specified in the German standard [16]. The tests were conducted using the protocol described by Millogo et al. [24] and Boubekeur et al. [25]. The values of the abrasion coefficient (C_A) were evaluated as the ratio of detached material to the brushed surface area according to Equation 4.

$$C_A\,(g/cm^2) = \frac{m_0 - m_1}{S} \qquad (4)$$

with S the brushed surface area and m_0 and m_1 the masses before and after brushing, respectively.

The German standard recommends measuring the mechanical strength of hardened earth plaster specimens by following standard EN 1015-11 [26] with slight modifications.

The 3-point flexural strength was determined on the prismatic specimens (40 x 40 x 160 mm^3) using R.M.U-Testing Equipment, Bergamo with a constant speed of 0.5 mm/min and a load of 50 N/s. The compressive strength of the specimens was evaluated on the six half-prisms obtained during the 3-point flexural test using a Controls multitester hydraulic press at a rate of 2400 N/s.

3. Results and discussion

3.1. Characterization of raw clayey material and cow dung

The particle size distribution of the soil sample is presented in Fig. 1.

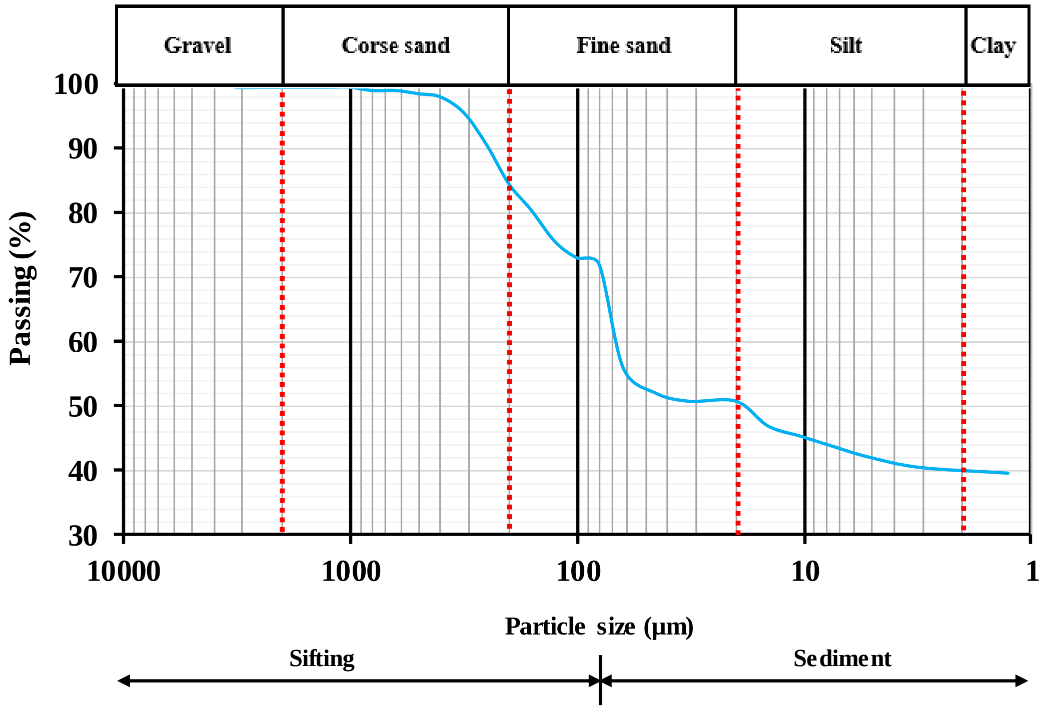

Fig. 1. Particle size distribution of the soil

The size distribution curve shows that the sample was composed of 16 wt.% of coarse sand, 34 wt.% of fine sand (20–200 µm), 10 wt.% of silt (2–20 µm) and 40 wt.% of clay (<2 µm). Considering the above results, it could be concluded that the sample was rich in fine fractions and was therefore suitable for making earth plaster [2-4]. The liquid limit (W_L), plasticity limit (W_P) and the plasticity index (I_P) of the sample studied were 44, 21 and 23%, respectively. Considering the methylene blue value (V_{BS} = 1.43 g/100 g), it can be concluded that the soil was clayey, sandy-loamy, and water sensitive, with medium plasticity [14].

The soil chemical composition is presented in Table 2.

Table 2: Chemical composition of the soil used in this study

Oxides	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOI[a]	Total
Wt.%	60.79	24.36	1.71	-	0.20	0.05	0.02	0.37	1.44	-	11.11	100

[a] Loss on ignition at 1000 °C

The sample contained large amounts of silica and alumina, and a small amount of iron oxides, which suggests that the clay soil would be rich in clay minerals, quartz and iron minerals.

The XRD pattern of the sample is presented in Fig. 2.

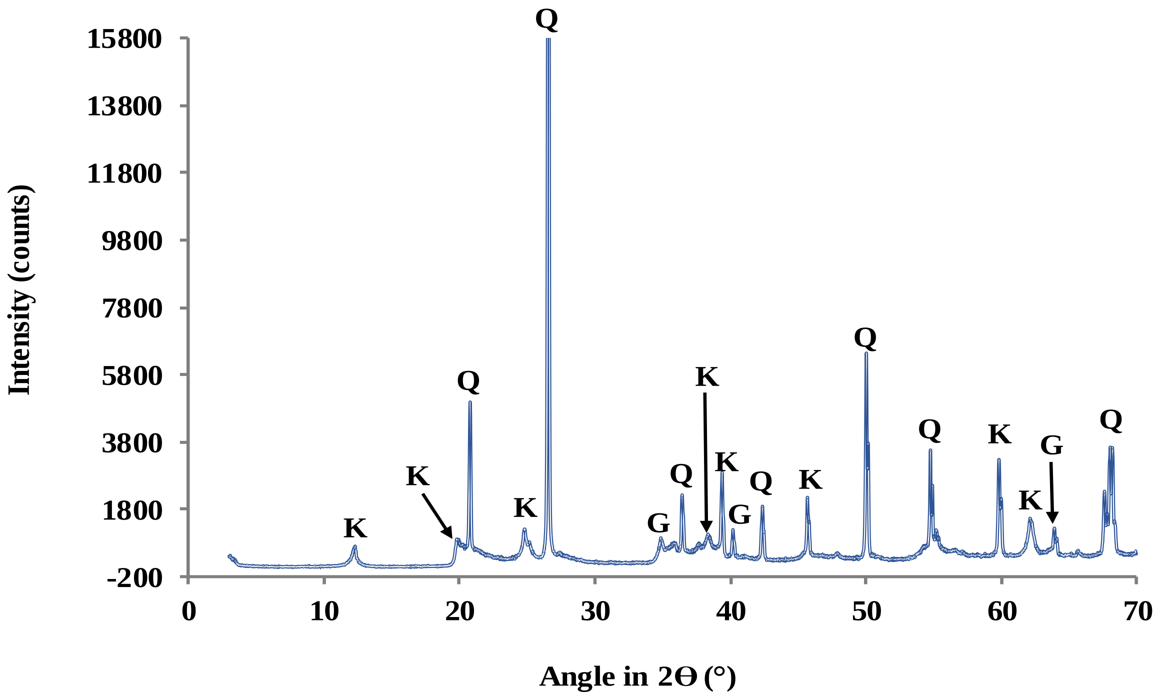

Fig. 2. X-ray diffraction pattern of the raw material (K: kaolinite, Q: quartz and G: goethite)

This X-ray diagram shows the presence of kaolinite ($Al_2Si_2O_5(OH)_4$), quartz (SiO_2) and goethite (FeO(OH)), a result well correlated with the chemical composition.

The IR spectrum of the raw material (Fig. 3) shows bands related to kaolinite: 3695, 3651 and 3622 cm^{-1} (O-H vibrations); 1027 cm^{-1} (Si-O-Si vibration); 1117, 1000 cm^{-1} (Si-O vibrations); 912 cm^{-1} (Al-OH vibration); to quartz (Si-O-Si vibration at 767 and 673 cm^{-1}) and to hygroscopic water (1637 cm^{-1}). The absence of the kaolinite band at 3672 cm^{-1} confirms its low crystallinity in the sample [23]. This is an important result as poorly crystallized kaolinite is more reactive than the well crystallized form.

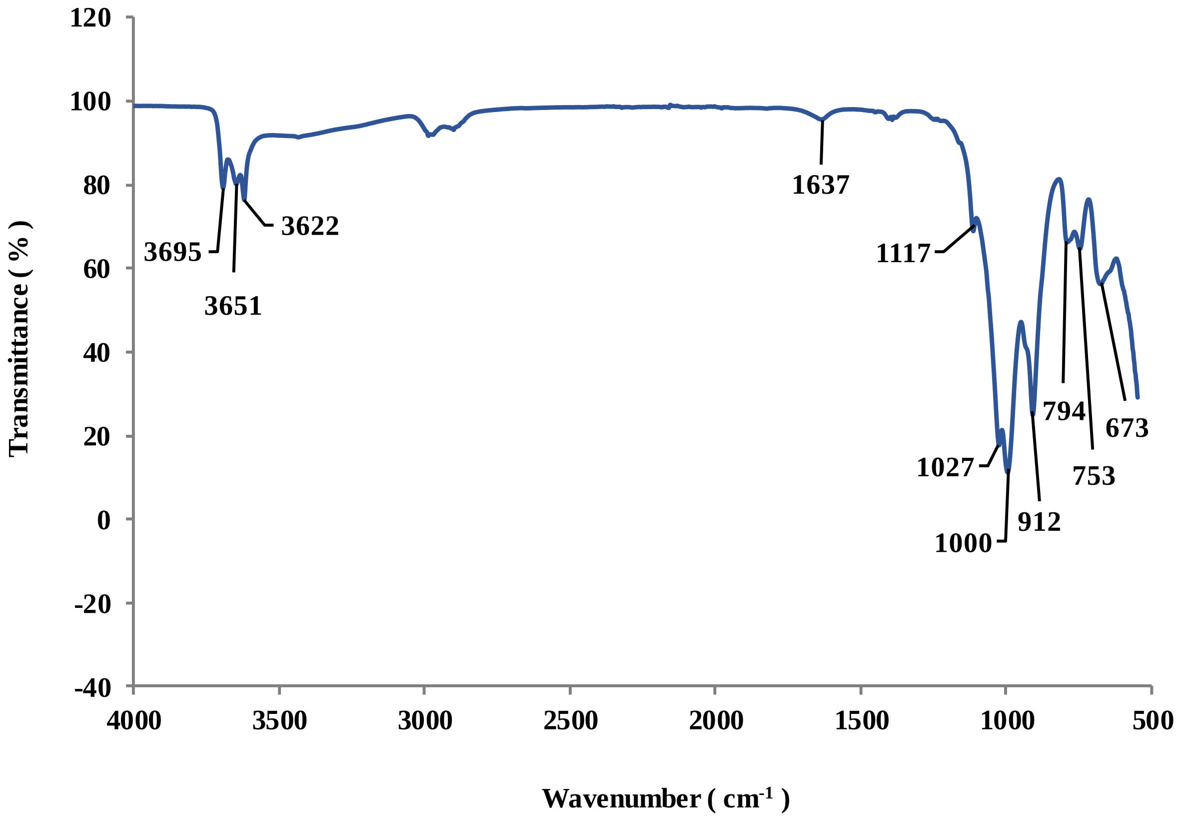

Fig. 3. FTIR spectrum of the raw material

The DSC and TGA curves of the sample are given in Fig. 4. They show an endothermic peak around 95 °C associated with a mass loss of 0.8 wt.% corresponding to the removal of adsorbed water. The strong endothermic phenomenon occurring at 500 °C is linked to the dehydroxylation of kaolinite. At this temperature, kaolinite dehydroxylation produces metakaolinite [27]. This is associated with a loss of mass of 8.1 wt.%. It appears at low temperature (less than 600 °C) because of the low crystallinity of the kaolinite, which could be disordered [23]. The weak endothermic peak around 578 °C is related to the transformation of quartz α to quartz β [28]. The last exothermic peak, around 970 °C, is attributable to the structural reorganization of metakaolinite.

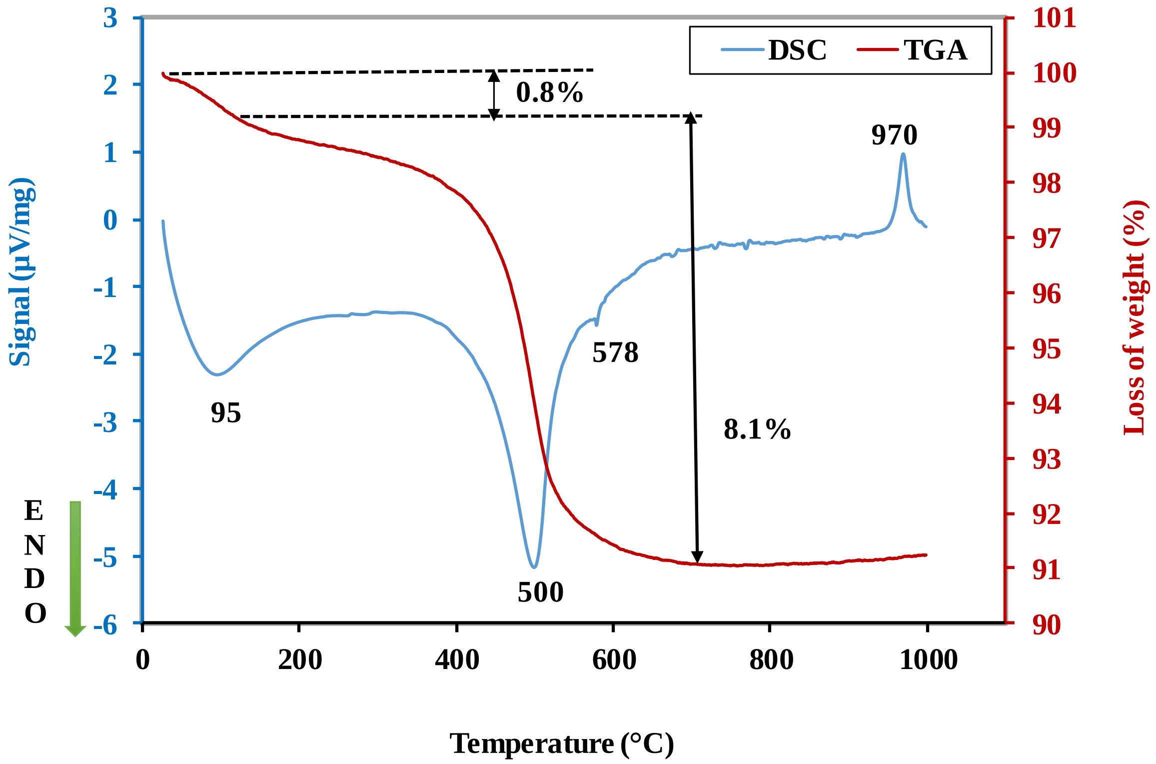

Fig. 4. DSC-TGA of the raw material

The quantitative mineralogical composition of the raw material was evaluated using Equation (2). The sample was composed of kaolinite (62 wt.%), quartz (31 wt.%) and goethite (2 wt.%). These results are well correlated with the sample grain size distribution, showing that the powder under study was rich in clayey material and sand (mainly quartz).

Scanning Electron Microscopy (SEM) observation coupled with energy dispersive spectrometry (EDS) analysis of cow dung is shown in Fig. 5. The SEM image of cow dung shows vegetable fibres, often in packets, which have not been digested by the cows. These fibres have a rough surface (Fig. 5a) that would favour good adhesion with the clay matrix and this could have a positive effect on the physical and mechanical properties of cow dung stabilized earth renders [29, 30]. Energy Dispersion Spectrometry (EDS) analysis of cow dung (Fig. 5b) showed that it contained mainly silica, alumina, calcium, potassium, magnesium, phosphorus, iron and sulphur. Plant fibres are the major components of cow dung.

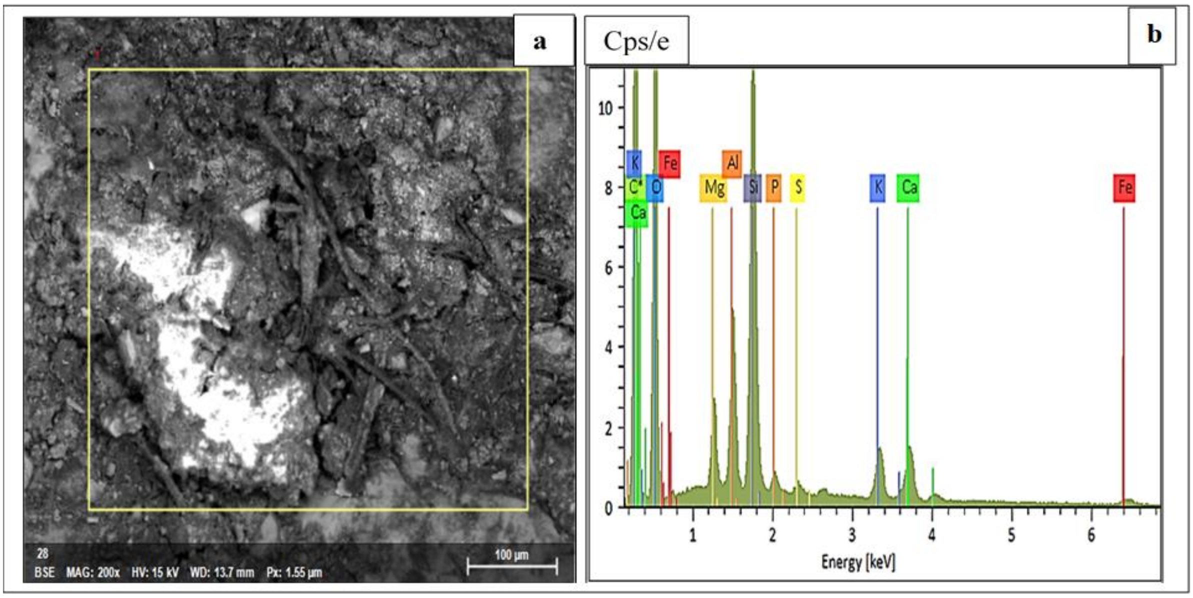

Fig. 5. Cow dung analyses by scanning electron microscopy and EDS

3.2. Microstructural characterization of earth plaster composites

To highlight the mechanism of cow dung action on the clayey matrix, the XRD patterns of earth rendering mortar amended with cow dung were observed after 90 days of curing. The overall analysis of these patterns did not show evidence of the formation of new crystallized phases but the intensity peak of kaolinite (basal peak) located at 12.36° and the quartz peak located at 26.6° decreased significantly with cow dung additions until an optimal value of 4 wt.% cow dung was reached (Fig. 6). The decrease of these peaks was due to the silica consumption of kaolinite silicates and fine crushed quartz. The phenomenon was made possible by the basic pH of the clay-cow dung mixture. The pH value, which is 7 for raw earth rendering mortars, reached 10.2 for clay-cow dung mixture with 6 wt.% cow dung. The increase of main peak intensities beyond 4 wt.% was due to the presence of excess non-consumed silica contained in the cow dung, as shown by EDS analysis.

According to Gashaw et al. [31], cow dung contains amine and, in general, tri-methyl amine ($(CH_3)_3N$). The fermentation of tri-methyl amine contained in cow dung by a biochemical process in the presence of bacteria induces the formation of methane, carbon dioxide and ammonia according to chemical equation 1:

$$4(CH_3)_3N + 6H_2O \rightarrow 9CH_4 + 3CO_2 + 4NH_3 \qquad \text{chemical equation 1}$$

In a basic medium, silica from low crystalline kaolinite or finely crushed quartz is attacked to produce silicic acid following chemical equations 2 and 3:

$$SiO_2 + 2OH^- \rightarrow H_2SiO_4^{2-} \qquad \text{chemical equation 2}$$

$H_2SiO_4^{2-} + 2H_2O \rightarrow Si(OH)_4 + 2OH^-$ chemical equation 3

The ammonia thus formed subsequently reacts with silicic acid to give amine silicate, is a water-insoluble compound, according to chemical equation 4:

$4NH_3 + Si(OH)_4 \rightarrow Si(OH)_4.\ 4NH_3$ chemical equation 4

The amine silicate molecule behaves as an adhesive because of the free electron pairs on the oxygen atoms and especially on the nitrogen atoms. This adhesive character of the molecule could improve the physical and mechanical properties of earth renders.

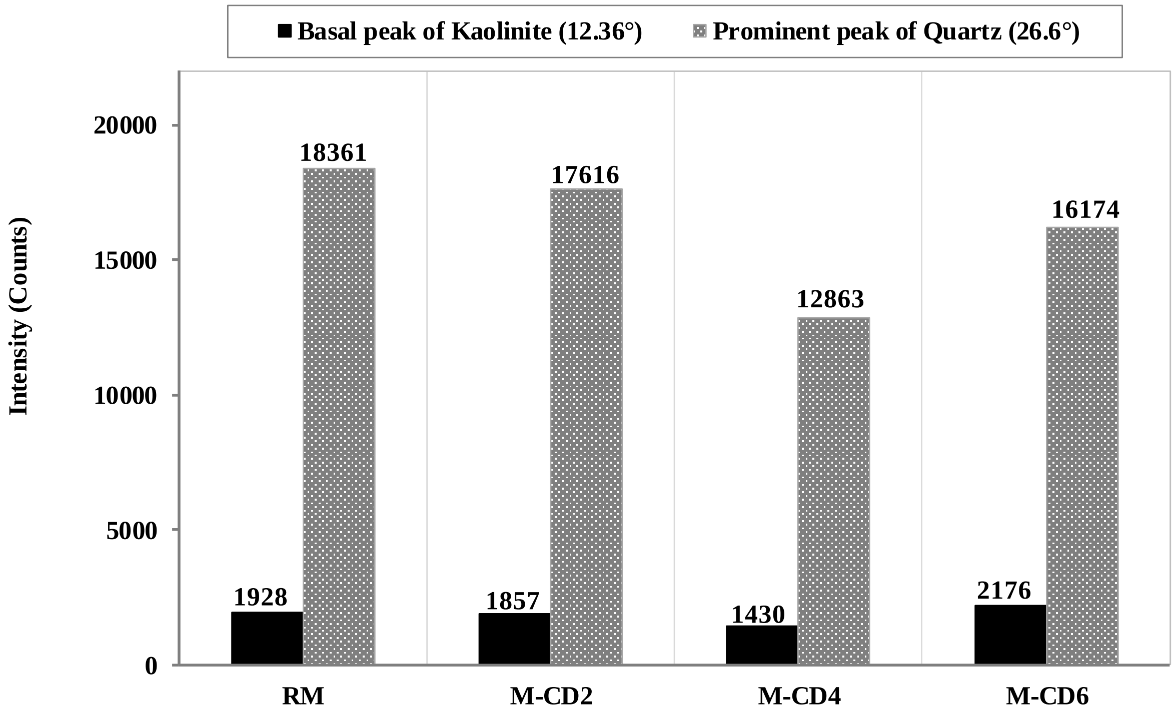

Fig. 6. Evolution of intensity peaks of kaolinite and quartz with cow dung additions

3.3. Physical and mechanical properties of earth rendering mortar reinforced by cow dung

The linear shrinkage of earth rendering mortars according to their cow dung contents is reported in Fig.7. The linear shrinkage decreases with cow dung additions. This result is due to the good adhesion of fibres with the clayey matrix, because of their rough surface, and to the presence of amine silicate, which links isolated particles from the soil by limiting shrinkage through chemical bonds created by free electronic pairs of oxygen and nitrogen. Similar results have already been reported in the literature on raw earth plasters reinforced with plant fibres [1, 3, 4, 6, 32]. The linear shrinkage measured on cow dung reinforced earth rendering mortars is less than 3 %, the maximum value of this parameter accepted for earth plaster according to the German standard [16]. Considering the above result, the earth rendering mortars made, even without cow dung, are suitable for dwellings and show no risk of causing damage.

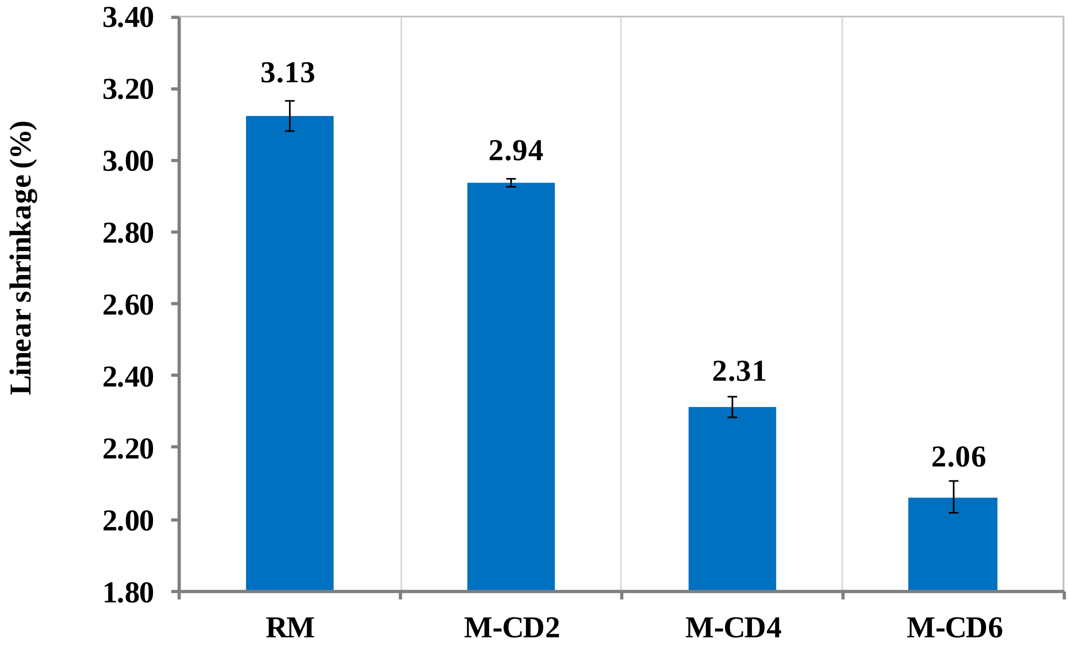

Fig. 7. Linear shrinkage of earth rendering mortars according to cow dung content

Table 3 shows the results for the apparent density and accessible porosity of the earth rendering mortars with cow dung additions. The apparent density decreases and the accessible porosity increases with these additions. The diminution of apparent density is due to the replacement of some soil particles by cow dung particles containing less dense vegetable fibres than those of soil. Similar results have been reported in the literature for clayey raw materials amended with natural fibres [4, 32-34]. When cow dung, rich in natural fibres, is added to the clayey matrix, these fibres can settle near the surface, creating accessible pores in different areas of earth renders. Such pores are accessible to mercury while the internal (closed) pores are filled with air. There is a good correlation between these two parameters. The same results have been reported by Ouedraogo et al. [10, 22] on adobes amended by kenaf fibres and fonio straw.

Table 3: Apparent density and accessible porosity of earth rendering mortars with cow dung additions

Earth rendering mortar	Apparent density (g/cm^3)	Accessible porosity (%)
RM	1.72	33.57
M-CD$_2$	1.66	35.81
M-CD$_4$	1.60	36.36
M-CD$_6$	1.56	36.68

The results for the weight of water absorbed per unit area of earth rendering mortar are plotted versus time in Fig. 8. The water absorption coefficients and the spray test results for mass loss of the earth renders are presented versus cow dung contents in Fig. 9. As shown in Fig. 8, different straight lines were observed, with correlation coefficients (R^2) greater than or equal to 0.98 in the time intervals explored, for the different earth renders elaborated. Considering the R^2 values, it can be concluded that there is good correlation between the water absorbed per unit area and the exposure time of the earth renders.

The water absorption coefficient decreases with cow dung additions, which lead to the formation of insoluble amine silicate (hydrophobic molecule). This glues isolated particles together through chemical bonds, making earth renders less permeable to water [9]. The latter result is also attributable to a decrease in the kinetics of capillary water upwelling through the material due the presence of fibres in the composite materials. Such evolution of the capillary water absorption coefficient was reported by Faria et al. [6]. To appreciate the behaviour of earth renders during the rainy season or for a wet climate, a spray test was carried out. Careful examination showed a diminution of loss of mass as cow dung was added. Raw earth render was more eroded than those amended with cow dung. This result was mainly due to the presence of insoluble amine silicate, which linked isolated soil particles and also created some chemical bonds with kaolinite sheets in the cow dung reinforced earth renders, making them waterproof. The good adhesion between the clayey matrix and fibres contained in the cow dung, together with their distribution within it, also contributed to this improvement [25, 34]. This behaviour of cow dung in earth renders can be considered as similar to that of the roots of plants that fight erosion by retaining the soil [32, 36, 37].

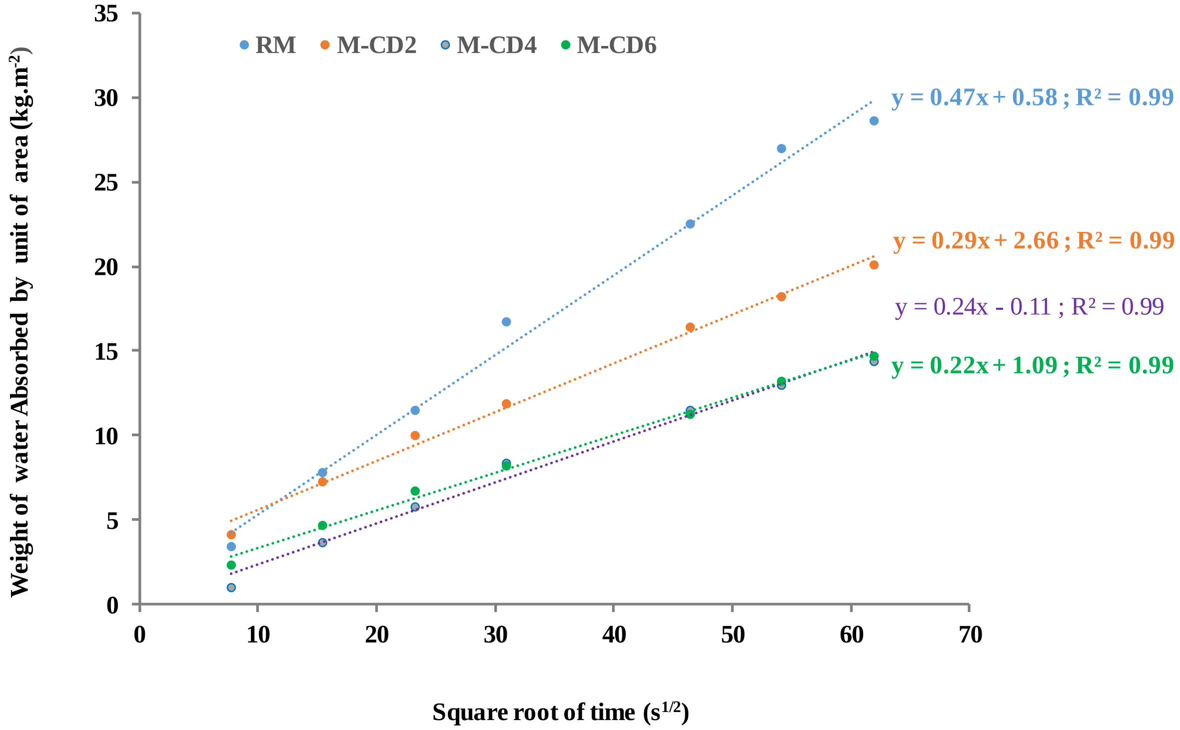

Fig. 8. Weight of water absorbed per unit area of earth renders versus time

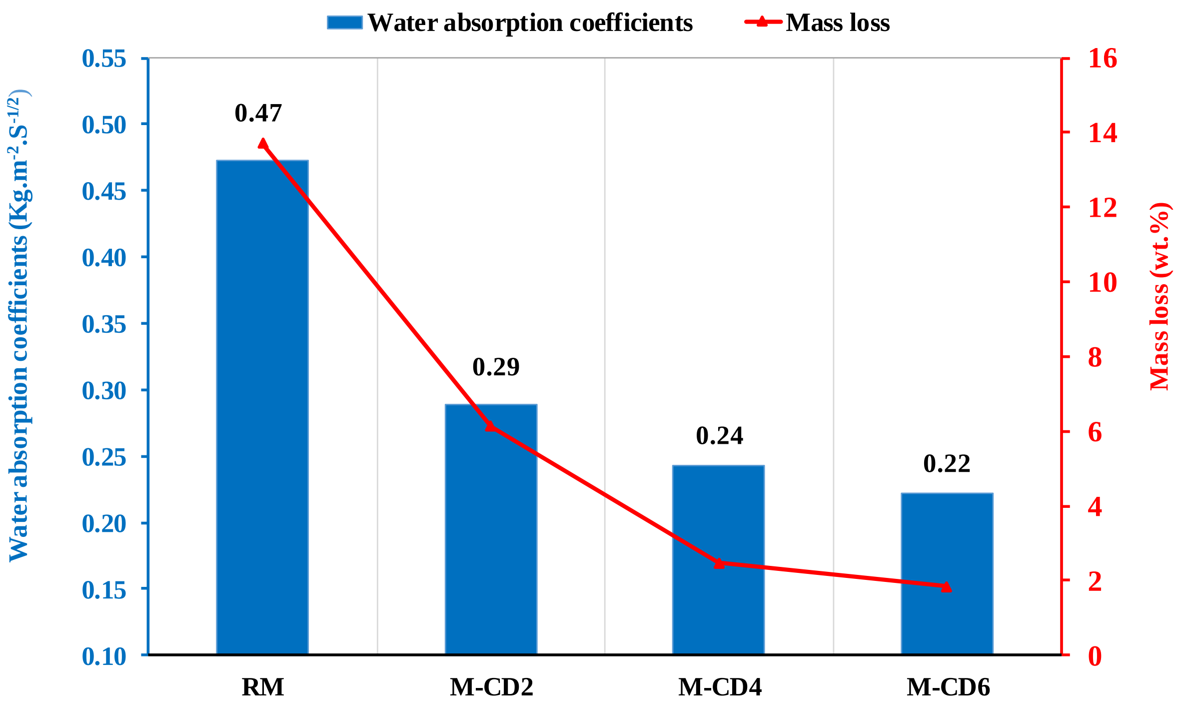

Fig. 9. Water absorption coefficients and mass loss of earth renders versus cow dung contents

The evolution of the thermal conductivity (λ) of earth renders with cow dung additions is presented in Fig.10. It can be seen to decrease as the cow dung content increases. This result is well correlated with the evolution of accessible porosity as cow dung is added. The decrease in λ can be explained by a combination of two effects: the increase of accessible porosity and the presence of vegetable fibres from cow dung, which contain large amounts of cellulose, a good insulation molecule that helps to decrease thermal conductivity [10, 22, 24, 37]. Overall, the thermal conductivity of cow dung reinforced earth renders is of the same order of magnitude as values reported in the literature concerning raw earth plasters or those reinforced by plant fibres [34, 38]. The low thermal conductivity of earth renders amended with cow dung is important for dwellings in dry climates such as that of the Sahel. This result means that significant savings can be made in energy linked to air conditioning and ventilation, which is a major problem for developing countries and particularly for the Sahel countries.

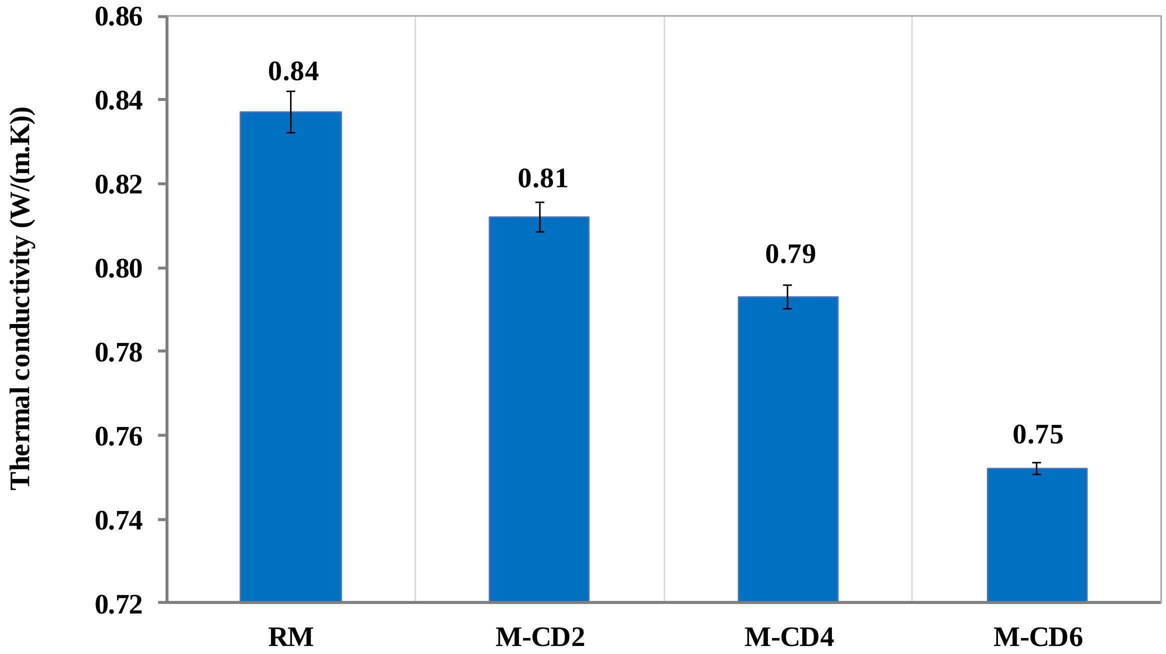

Fig. 10. Thermal conductivity of earth renders

Fig.11 shows the evolution of the abrasion coefficient of earth renders versus cow dung content. The abrasion coefficient decreases with cow dung additions, a result linked to the good cohesion between soil particles and the vegetable fibres contained in the cow dung because of their rough surface. As for the physical properties mentioned above, the decrease of the abrasion coefficient is due to the linkage of isolated soil particles provided by the formation of amine silicate, which has an adhesive property. The results of this study could be compared with those for Pressed Adobe Blocks (PABs) stabilized by long fibres (6 cm) of

Hibiscus cannabinus [24], which exhibited better abrasion coefficients than earth renders reinforced with cow dung containing short fibres: the adhesion between clayey matrix and vegetable fibres is better with longer fibres. According to the German standard [16], the results found in this study classify the earth renders in the SI category (abrasion category having a mass loss of less than 1.5g per cm^2). The effect of cow dung is very clear: a diminution of abrasion of 61% is observed between raw earth renders and those amended with 6 wt.% of cow dung.

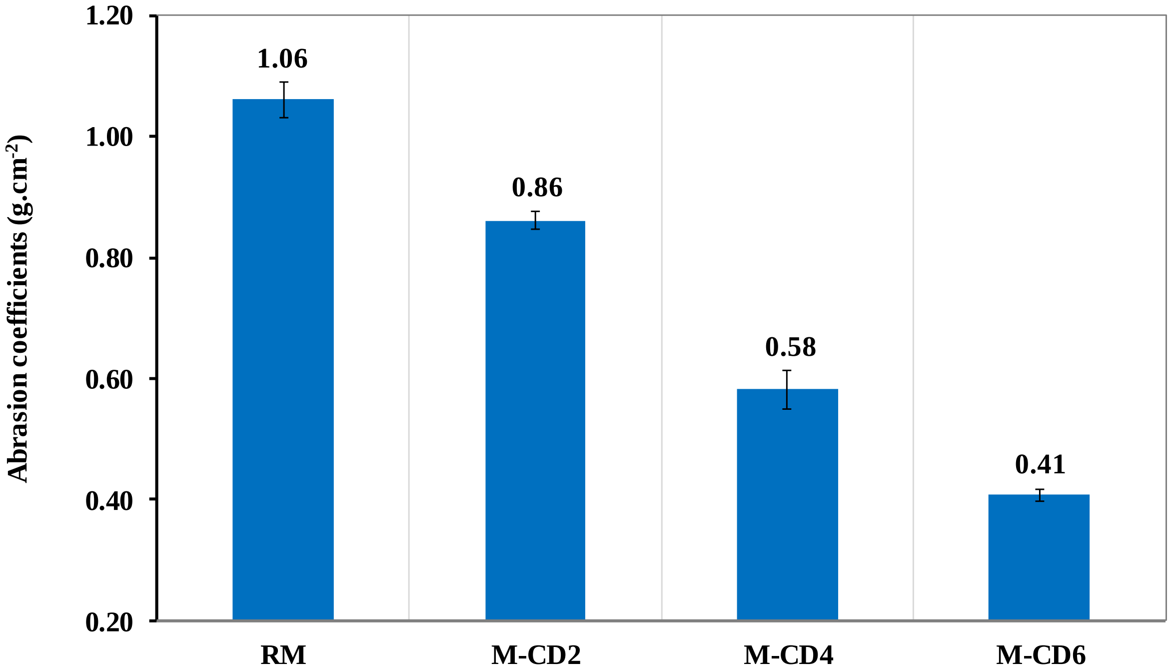

Fig. 11. Abrasion coefficient of earth renders versus cow dung content

The compressive and flexural strengths of earth rendering mortars with cow dung additions are shown in Fig.12. These two parameters increased with cow dung additions. These results can be explained by the formation of insoluble amine silicate, which binds the isolated particles of raw materials together. The improvement in compressive strength was also due to the presence of fibres in cow dung, which prevented the propagation of cracks in the clayey matrix thanks to the good adhesion of their rough surfaces with this matrix [9, 39-42]. This explains why the compressive strength increases despite the decrease in the amount of amine silicate formed for high proportions of cow dung. The increase in flexural strength was due to two conjugated effects: the presence of fibres rich in cellulose, a crystalline molecule with good tensile strength [9, 24, 43], and the formation of amine silicate, which glues isolated soil particles together.

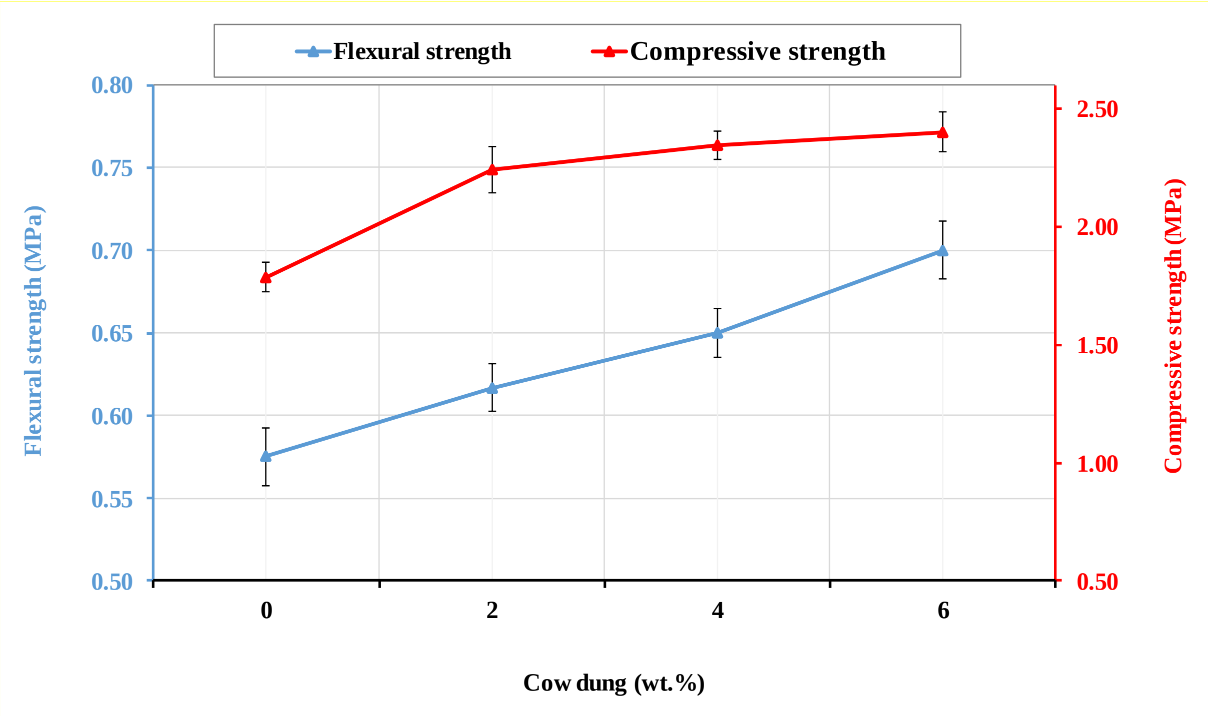

Fig. 12. Flexural and compressive strengths of earth rendering mortars reinforced by cow dung

The mechanical resistances obtained in this study are higher than those of earth plasters amended with plant fibres or plant aggregates [3, 33, 44]. These differences could be linked to the difference in the grain size distribution and the mineralogical composition of the soils used in this case, the quantities of clay minerals because the presence of a large clay fraction is necessary for the formation of the insoluble amine silicate that improves the mechanical properties. The mechanical resistances obtained in this study are similar to those reported by Millogo et al. [9] for the stabilization of earth blocks with cow dung. This similarity is related to the length of the fibres (the fibres in cow dung are short) because the soil used for earth renders has almost the same grain size distribution and mineralogical composition as that used for earth blocks.

It is possible to compare the mechanical properties obtained in this study with the range of mechanical characteristics established by Veiga et al. [45] for plasters, renders, and bedding mortars for historic constructions. It can be concluded that the cow dung amended earth renders meet the requirements of compressive and flexural strengths defined by the researchers. Thus, the mechanical properties obtained in this study are consistent with the range defined for earth renders for masonry.

4. Conclusions

The influence of cow dung on the microstructure, the physical characteristics and the mechanical properties of earth renders manufactured with a clayey soil in Burkina Faso has been investigated in this work. The mineralogical characterization of the clay used as a raw material for the manufacture of earth renders showed that it was mainly composed of kaolinite (62 wt.%), quartz (31 wt.%) and goethite (2 wt.%). In terms of its geotechnical properties, this clay is suitable for use in the manufacturing of earth renders. The cow dung characterization used in this study showed that cow dung consists mainly of plant fibres of various small sizes and contains clay minerals and quartz consumed by cows in small proportions. The cow dung and soil addition induced the formation of insoluble amine silicate following the reaction of cow dung with kaolinite (its silica silicates) and fine crushed quartz. This compound glues the isolated particles of the soil together, thus making the earth renders more compact. Earth renders containing cow dung are resistant to water erosion and have low thermal conductivity. The formation of insoluble amine silicate contributes to the improvement of physical and mechanical properties. This study has permitted some scientific explanations to be put forward for the efficiency of the vernacular practice of adding cow dung to earth renders to improve their durability, especially their water resistance. In view of all these microstructural, physical and mechanical characteristics, earth renders containing cow dung are suitable for building coverings because they regulate the temperature inside the buildings. This will enable poor populations to live in homes with good thermal comfort. This will logically reduce energy expenditure because fans and air conditioners will be used less during hot periods, which cover three quarters of the year in dry tropical countries such as Burkina Faso. This result is very important for developing countries because it means that less well-off people will be able to protect their homes with water-resistant earth renders reinforced with cow dung, thus avoiding the use of renders made with a sand-cement mixture, which are expensive because of the price of cement.

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