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Effects of rice husk on adobes in clay soils

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Abstract

This work aims to evaluate the influence of rice husk on the mechanical and physical characteristics of adobes produced from clay soils. To this end, rice husk sorted by a 1.25mm diameter mesh screen was used to formulate different mixtures comprising 0%, 1%, 1.5%, 2% and 2.5% by mass of clay. The specimens with dimensions of 4cmx4cmx16cm were produced after 0, 7 and 14 days of maturation of the formulated pastes. The different adobes were tested for water absorption, drying shrinkage and mass loss as well as for mechanical characterization. The results obtained indicate that the linear shrinkage, mass loss and water absorption coefficient decrease with increasing percentages of rice husk and days of maturation. The addition of 1% rice husk to these clay soils improves the mechanical strength. This improvement is a function of the number of days of maturation of the pasta and leads to a gain of 5 to 6% in mechanical strength for the clay soil of N'Djamena.

Keywords: Adobes, Rice husk, Mechanical resistance, Absorption, Linear shrinkage.

Introduction

In the construction sector, the depletion of natural resources, the increase in the price of raw materials, the protection of the environment against the emission of greenhouse gases, are prompting researchers and engineers to look at alternative building materials to achieve certain sustainable development objectives. Raw earth is an eco-material that could be one of the alternative materials. As old as the world, earth is a building material that has been used by humans throughout the ages for many millennia[1]. At least one third of the world's population lives in earthen houses[2]. This shows its importance in the construction sector.

Among the five (5) main earthen construction techniques we have adobe. Adobe is a mixture of clay, water, sand and sometimes vegetable fibers, produced by hand, with rectangular moulds. It is a 100% natural, economical, recycling, hygroscopic, local, ecological and low energy consuming material[3-5,6]. Adobe constructions are widespread in Chad in most villages and on the outskirts of large cities[7,8].

Rice husks are used in clay soil to coat the exterior of mud brick houses. Plant fiber reinforced materials are composite materials that have the characteristics of eco-materials. These materials meet the technical criteria of functional performance, durability, safety, heat resistance, and their use should not generate any negative impact on human health or the environment. Rice is grown in several provinces in Chad, and the rice husk can be valorized to support economic development. The evaluation of the effect of these husks in adobes could be a starting point to valorize this agricultural by-product in the construction sector. This is the purpose of this work which focuses on the presentation of some characteristics of the materials used, notably clay and rice husks; the different formulations of the specimens of dimensions: 4cmx4cmx16cm; the description of the water absorption, linear shrinkage, bending and compression tests, carried out in the laboratory as well as the experimental results obtained

Materials and methods

Materials: The raw materials used for this work are clay soils from Moundou (8°34'0.001"N 16°4'59.999"E) and N'Djamena (12°47.001"N 15°2'57.001"E) in Chad and rice husks from Mara, a village near N'Djamena. The clay soils of Moundou (MOD) are class A2 low plastic clays and those of N'Djamena (NDJA) are class A2/A3 low plastic clays. Their respective organic matter contents are 5.11 and 2.71 with a loss on ignition of about 6.

The rice husks used to amend the mud bricks have a sieve of 1.25mm diameter. The ash content in the rice husk expresses the presence of minerals not consumed at less than 600°C. It is 22.77%, which is consistent with the range of ash contents that vary from 17 to 26% [9]. The tannin content is 3.4% in the rice husk. Figure-1 shows the physical aspect of the materials used.

Methods: Water absorption of rice husks: Bio-based materials have a very high water absorption capacity[1]. The water absorption capacity is an important parameter for a plant fibre, especially rice husks. The work of Magniont[3] and Tai Thu[4] was used as a basis to determine the absorption rate of these rice husk series. For this purpose, 1g of the 1.25 mm series was taken from the rice husk after it had been baked at 105°C for 24 hours. This temperature is used for drying rice straw[1]. For drying wood[10], the samples were immersed in distilled water for 5 min, 10 min, 15 min, 30 min, 60 min and 120 min. At the end of each immersion time, the water adsorbed on the surface of the rice husks as well as the interstitial water between them was removed by manual shaking. The absorption rate A (%) of the rice husks was determined using the following equation:

$$A\ (\%) = \frac{m_t - m_0}{m_0} \times 100 \quad (1)$$

m_t: mass in grams (g) of the sample immersed in water for a period of time t; m_0: mass in grams (g) of the sample dried in the oven for 24 hours.

Composition of the mixture of clayey soils and rice husks for the tests: The formulation of adobes consists of determining the different proportions of the elements that constitute the composite. Several authors claim that the incorporation of fibres in the raw earth increases the mechanical strength of adobes. Bobet[11] had used peanut shells cut from 0.33cm to 3cm to reinforce the adobes in proportions ranging from 1.8% to 3% with a pitch of 0.4% and powders of the same shell from 5% to 20% with a pitch of 5% to reinforce the adobes. Bouhicha et al[12] and Abakar[1], respectively, used straw in proportions of 1.5% to 3.5% with a 1% pitch and rice straws with percentages of 0.5% to 1.5% to make compressed earth bricks.

Based on the above mentioned work of these authors, we adopted the formulation according to Tables-1, 2. The mass percentage of clay in the 1.25mm series ranges from 1% to 2.5% with a step of 0.5%. For each formulation, the clay-rice husk mixture is first dried, then the initially measured mixing water is added gradually until a malleable mixture is obtained. Each addition of water is followed by mixing. The water content is calculated by dividing the mass of water used for mixing by the mass of dry soil. The water content of the mixture increases with the proportion of rice husk (Figures-2, 3), and the presence of sand significantly reduces the water content, although it depends on the proportion of rice husk. In Tables-1, 2, A: clay, B: rice husk and S: sand.

Figure-1: a- MOD clay soil sample, b- NDJA clay soil sample, c- burnt rice husk, d- unburnt rice husk.

Table-1: Formulation of the clay soil of Moundou with rice husks of 1.25 mm for adobes.

Without sand			With sand		
Mixture composition	Reference	Water content (%)	Mixture composition	Reference	Water content (%)
100%A-0%B	D0	38,6	80%-20%S-0%B	ASM0	34,0
99%A-1%B	D1	38,7	99%ASM_0-1%B	ASM1	34,1
98,5%A-1, 5%B	D2	39,1	98,5%ASM_{0-}1,5%B	ASM2	34,1
98%A-2%B	D3	39,9	98% ASM_0-2%B	ASM3	34,2
97,5%A-2,5%B	D4	38,8	97,5%ASM_0-2,5%B	ASM4	34,4

Table-2: Formulation of the N'Djamena clay soil with 1.25 mm rice husks for adobes.

Without sand			With sand		
Mixture composition	Reference	Water content (%)	Mixture composition	Reference	Water content (%)
100%A-0%B	N_0	24,4	80% -20%S-0%B	AS0	34,0
99%A-1%B	N_1	24,7	99% AS0-1%B	AS1	34,1
98,5%A-1,5%B	N_2	25,5	98,5%AS01,5%B	AS2	34,1
98%A-2%B	N_3	26,3	98% AS0-2%B	AS3	34,2
97,5%A-2,5%B	N_4	27,8	97,5%AS0-2,5%B	AS4	34,4

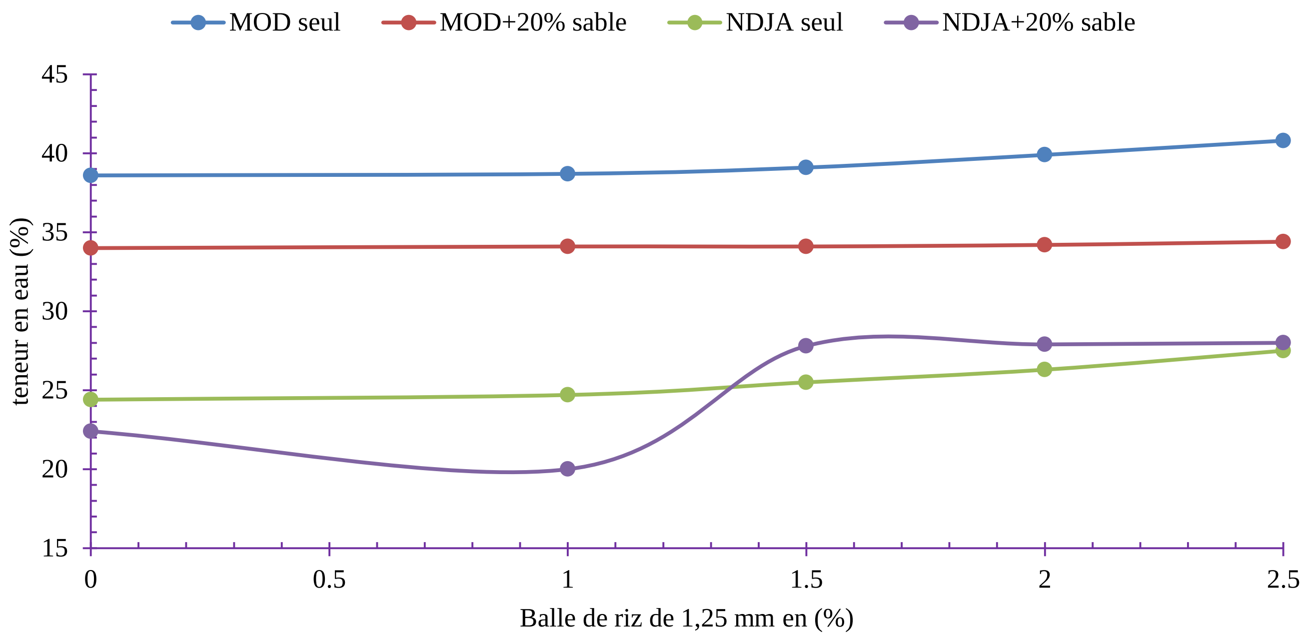


Figure-2: Variation of moisture content with percentage of 1.25 mm rice husks for adobes.

In the following, the study will focus on the mixtures without sand.

Preparation of the samples: The soils were sun-dried, hand-scraped and then sieved. According to NF P13-901[13], the 5mm sieves were mixed with the initially dried rice husks and water according to the different formulations. The mixtures are homogenised and then kneaded for 10 to 15mm to obtain the pastes. These pastes are moulded in metal prismatic moulds of 4cmx4cmx16cm (Figure-3) immediately, seven (7) days after or fourteen (14) days of maturation. During the curing period, the doughs are kneaded regularly every three (3) days. The inside of the moulds is first coated with oil and then filled with pasta. The whole set is placed on the electric shock table (Figure-4) where it is subjected to sixty (60) shocks at a time according to its instructions. After being removed from the shock table, the moulded pasta is demoulded. Demoulding is carried out after 24 hours in the test room. The resulting adobes are dried for at least 28 days in the test room.

Figure-3: Metal mold used to make adobes.

Figure-4: Device for the production of adobes.

Linear Shrinkage and Mass Loss of Adobes: The determination of linear shrinkage and mass loss of the specimens is based on the work of Bobet[11]. According to Bobet, the dimensional variations and mass loss of adobes are determined according to the standard that conventionally applies to bricks. The dimensions and mass of adobes are determined at one (1) day, ten (10) days and twenty (20) days after demoulding. Shrinkage and mass loss are determined by equations (2) and (3) respectively.

$$R\ (\%) = \frac{l_0 - l_t}{l_0} \times 100 \qquad (2)$$

$$M\ (\%) = \frac{m_0 - m_t}{m_0} \times 100 \qquad (3)$$

R and M: relative linear shrinkage and mass loss;

l_0 and m_0: length of the specimen at the time of molding, corresponds to the nominal length of the mold (16 cm) and mass of the specimen at demolding;

l_t and m_t length and mass of the specimen after twenty 20 days of drying.

Measurement of the water absorption coefficient of adobes by capillarity: The water absorption test consists of placing the samples on a bed of gravel and immersing them in water for about 5 mm (Figure-6) after being baked at 105°C for at least three hours, according to the work of Ouédraogo[14]. In order to avoid any degradation, the immersed part is covered with a filter paper (Figure-5). The test was carried out according to the AFPC-AFREM protocol[15]. The masses of the immersed specimens increase with time, reflecting the absorption of water. The mass of each immersed specimen was measured at 5, 10, 15, 30 and 60 minutes, referring to the work of Magniont[3]. The water uptake of adobes is determined by equation (4):

$$A\ (kg/m^2) = \frac{m_i - m_0}{S} \qquad (4)$$

m_0: mass of the dried test piece, m_i : mass of the test piece after a time t of immersion. m_i : mass of the test piece after a time t of immersion.

Figure-5: Placing of filter papers.

Figure-6: Device of water absorption of the specimens.

Three-point bending test: Prismatic specimens of nominal dimensions 4cmx4cmx16cm, manufactured and dried for at least 28 days, are used for the three-point bending test according to NF EN 12390-5 [16]. The press used is manually operated. The specimens were loaded (Figure-7) at a speed of 0.025mm/s until they broke into two equal parts (Figure-8). The principle of load application is illustrated in Figure 9. For each specimen subjected to three-point bending, the breaking load is recorded and then the evaluation of the bending strength is carried out using equation (5).

$$R_f = \frac{3.F.l}{2.d_1.d_2} \qquad (5)$$

R_f: bending strength in megapacals (MPa); F: maximum breaking load of the specimen in Newton (N); l: distance between the two support rollers, in millimeter (mm); d_1, d_2: dimensions of the cross-section of the test piece, in millimeter (mm);

Figure-7: 3-point flexing device.

Figure-8: Rupture of a specimen in two parts.

Compression test: After each 4cmx4cmx16cm specimen is broken into two pieces, the two pieces are recovered and subjected in turn to compression (Figures-9, 10) in accordance with NF EN 12390-3 [17] at a loading rate of 0.03mm/s. The values of the loads at failure are recorded on a computer. The compressive strength of each piece is calculated by the relation (6). According to the laboratory protocol, the average of the two compressive strengths represents the strength of the specimen.

$$R_c=\frac{F}{A_c} \quad (6)$$

R_c: bending strength in MegaPacals (MPa); F: maximum breaking load of the specimen in Newton (N); A_C: cross-sectional area of the specimen, in square millimeters (mm²).

Figure-9: Device for compressing adobes.

Figure-10: Adobe crushed by compression.

Results and discussion

Water absorption by the rice husk: The water absorption of plant fibers depends on the immersion time[1,14]. The curve in Figure-11 shows the water absorption of rice husk as a function of time. In ten (10) minutes, it is 125% and from 60 minutes the increase is very small. At 120 minutes it is 255%. The increase in water absorption by plant fibres is favoured by their hydrophilic character[14]. Ouédraogo M.[13] found a rate of 235% when he immersed Kenaf fiber in 24 hours, while for rice stalks[1], he obtained 271% for the same duration. This indicates that water absorption by plant fibres depends on the type of fiber but also on the amount of fiber put into the water[18].

Linear shrinkage and mass loss of adobes: Figure-12 shows the variation in linear shrinkage and loss of mass of adobes during drying. Both quantities vary with the percentage of rice husk. The linear shrinkage decreases as the percentage of rice husk in the adobe increases. The opposite phenomenon is observed for the mass loss. The author of reference[11] obtained the same results using peanut powders respectively. The linear shrinkage and mass loss of the MOD soil adobes are higher than those of the NDJA soil. The result presented in Figure-13 shows that the linear shrinkage decreases when the fibre content becomes high or when the maturation time of the formulated pastes becomes long. At the 14th day of maturation for an absorption of 2.5% the N'Djamena soil is stable.

Water absorption coefficient of adobes by capillarity: Specimens made with 1.25mm rice husk reinforcement with 0%, 1%, 1.5%, 2%, 2.5% by mass of soil are produced on the same day (0 day), at 7 days and at 14 days of maturation. These specimens are immersed in water. After the measurements of the absorbed water masses, the curves are plotted for each day of maturation. Figures-14, 15 show examples of linear trend curves obtained from the water uptake curves of adobes at 0 days of maturation. They show that water uptake increases with the square root of time. The evolution of this absorption is linear as a function of the square root of time. The same results were obtained by Bobet[10] and Magniont[3]. We found that the directing coefficient of the lines, which corresponds to the absorption coefficient expressed in $kg/m^2.s^{1/2}$, decreases when the percentage of rice husk increases or when the days of maturation of the formulated clay-rice husk mixes increase (Figure-16). Figure-16 shows the evolution of this water absorption coefficient of the adobes as a function of the rice husk content of 1.25mm and the maturation time. In general, the two soils used for the adobes produced on the 14th day of maturation of the pasta have low absorption coefficients. However, the MOD soil has a higher absorption coefficient than the NDJA soil for the 14 days of maturation. According to Paulus J.[19] the capillary water absorption of adobes is a function of their age, clay content and the percentage of fibers used in the formulation, the absorption study leads to the same conclusions.

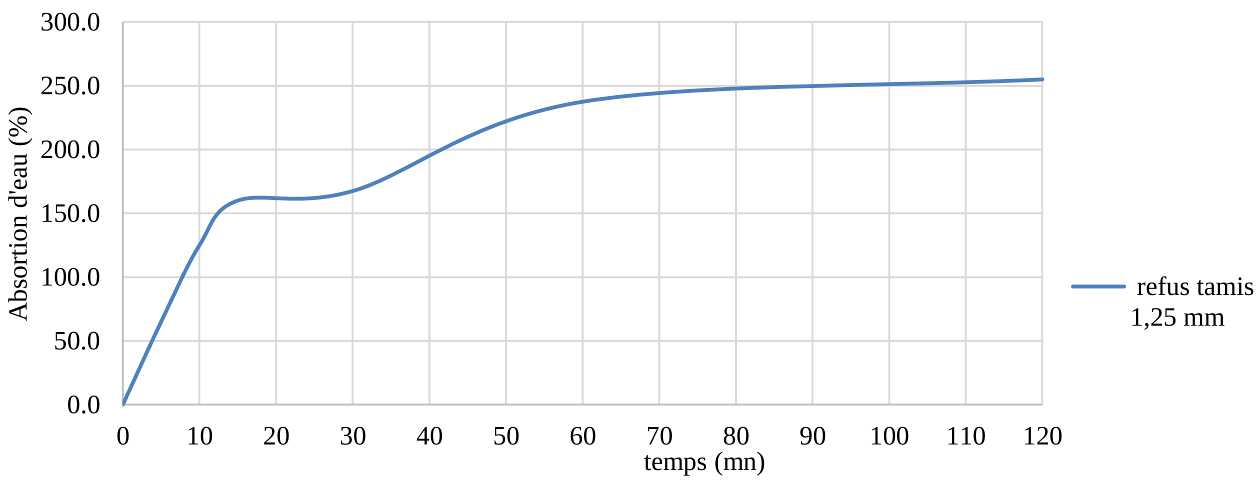


Figure-11: Water absorption curve for 1.25 mm rice husks.

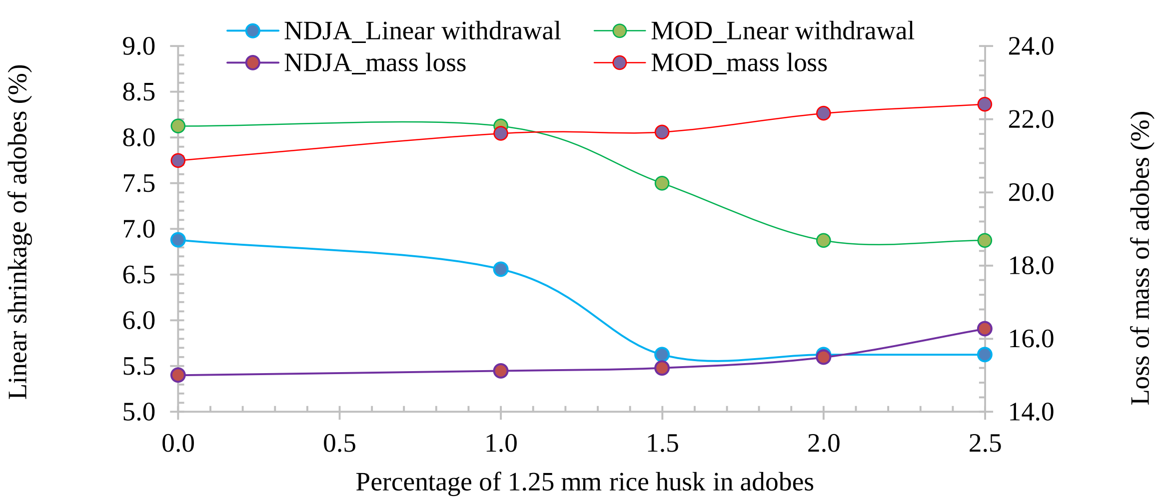
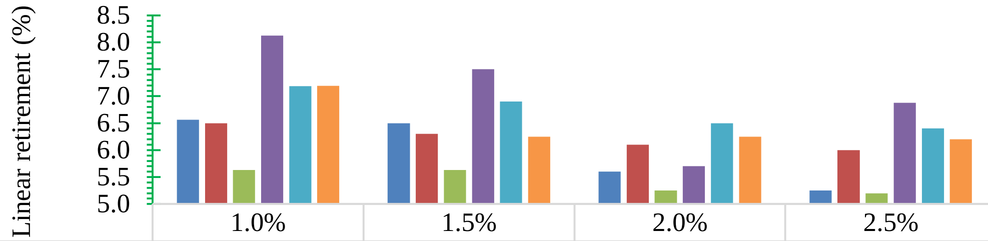


Figure-12*:* Evolution of adobe retirement as a function of 1.25 mm rice husk dosage.



	1.0%	1.5%	2.0%	2.5%
NDJA_0 day	6.6	6.5	5.6	5.3
NDJA_7 days	6.5	6.3	6.1	6.0
NDJA_14 days	5.6	5.6	5.3	5.2
MOD_0 day	8.1	7.5	5.7	6.9
MOD_7 days	7.2	6.9	6.5	6.4
MOD_14 days	7.2	6.3	6.3	6.2

Figure-13: Evolution of linear shrinkage of adobes as a function of maturation days and 1.25 mm rice husk dosage.

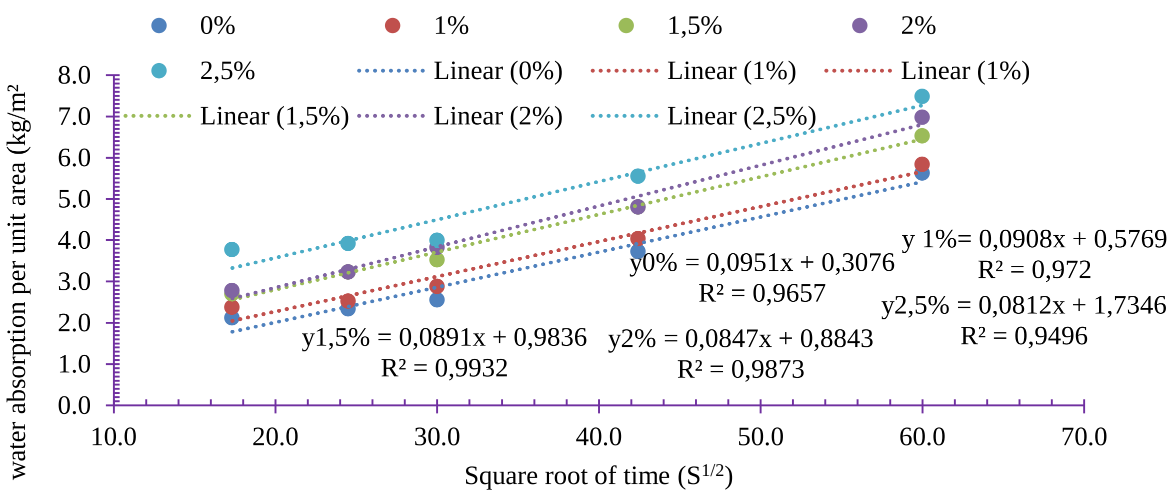


Figure-14: Water absorption of adobes without maturation with NDJA as a function of 1.25 mm rice husk content.

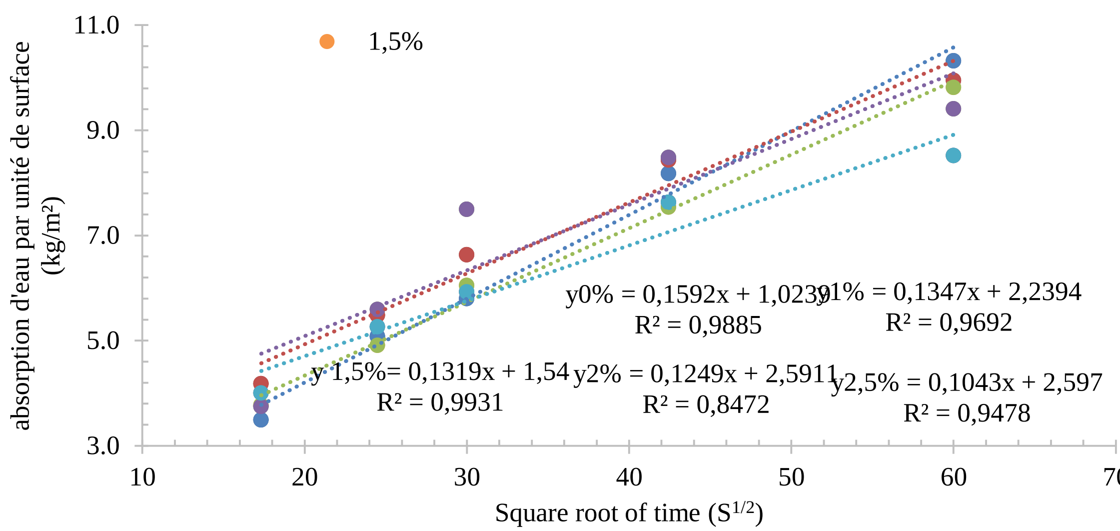


Figure-15*:* Water absorption of unripened adobes with MOD as a function of rice husk content 1.25mm.

Three-point bending strength and compressive strength: Figure-17 shows the evolution of the three-point bending strength and compressive strength of the adobes with 0 days of maturation of the pastes. For an addition of 1% rice husk, the mechanical strengths are significantly improved for both soils. Beyond the addition of 1% rice husk 1.25 mm these strengths drop. This improvement could be explained by the fact that with the percentage of rice husk, the adobes are less porous. Similar results were observed by Ouédraogo M.[14] and Bobet O.[11], but for different proportions of vegetable fibers. Furthermore, it is noted that with the same proportion of rice husks, the NDJA soil gives a better result in mechanical strength, which shows that the mechanical characteristics (Figures-17, 18, 19) also depend on the type of clay matrix of the soil.

Figures-18, 19 show respectively the three-point bending strength and the compressive strength of the adobes of the clayey soil of N'Djamena and Moundou at different days of maturation of the formulated pastes and at different formulations with 1.25mm rice husk. Figure-18 shows that the three-point bending and compressive strengths of the adobes increase with the maturation time of the formulated pastes. The maturation of the pasta favored the reactions of complexassions between the polyphenols from the rice husks and the clay matrix, which contributed to the improvement of the adobe characteristics. On the 14th day of maturation, the compressive strength is maximum, which corroborates Jeanne P's statement[18] that the lower the capillary absorption of an earth brick, the better its durability. The optimum value in compression is observed in Figures-18, 19 at different days of maturation for a rice husk content of 1% by mass. For higher rice husk contents, the mechanical strength values become low.

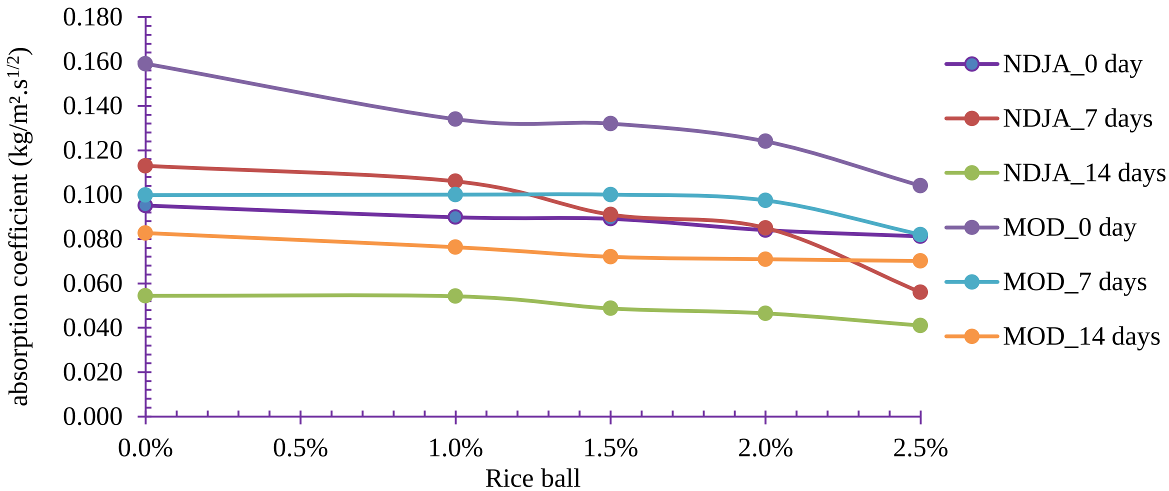


Figure-16: Water absorption coefficient of adobes as a function of 1.25 mm rice husk content and number of days of maturation.

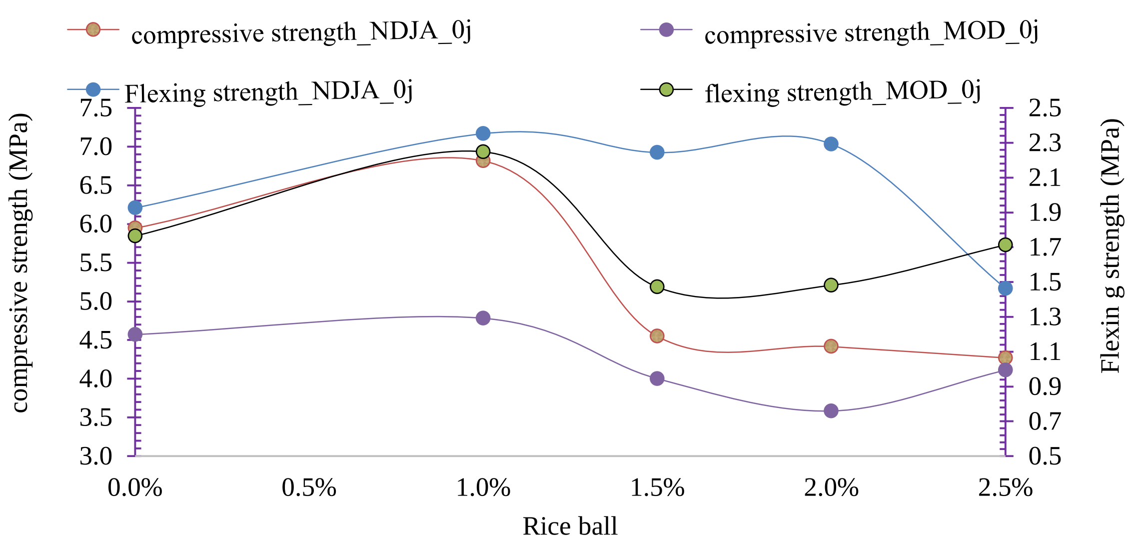
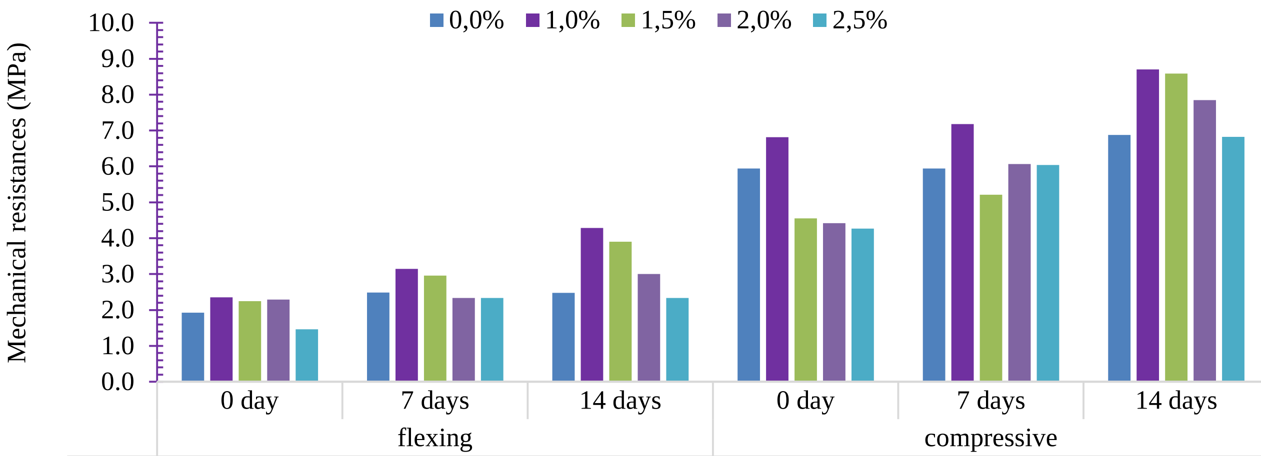
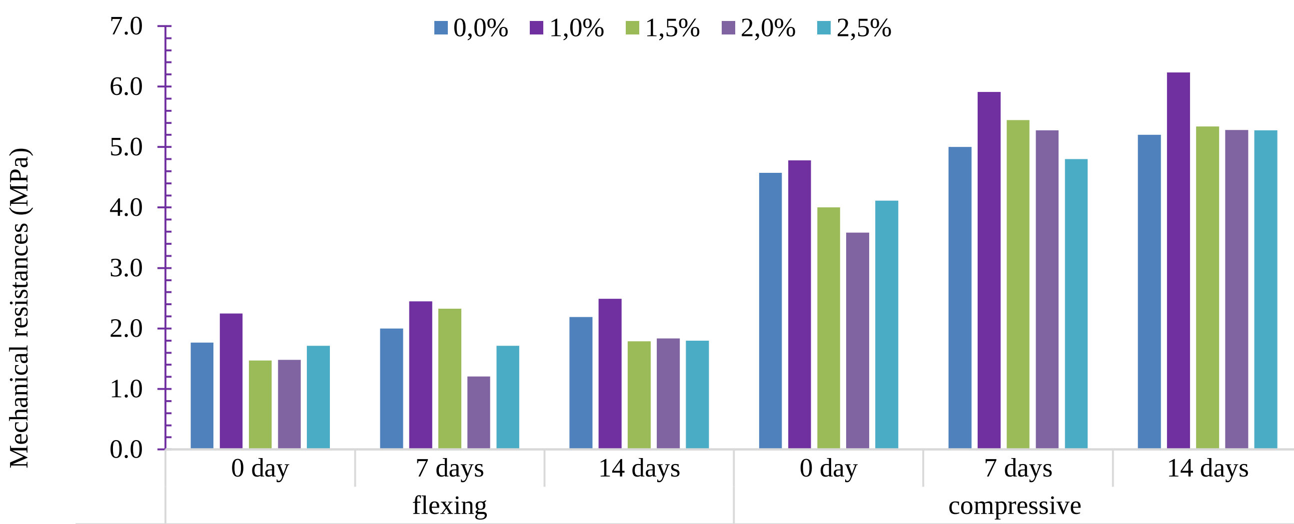


Figure-17: Three-point bending strength and compressive strength of adobes at 0 days of maturation.



	0 day (flexing)	7 days (flexing)	14 days (flexing)	0 day (compressive)	7 days (compressive)	14 days (compressive)
0,0%	1.9	2.5	2.5	5.9	5.95	6.9
1,0%	2.4	3.1	4.3	6.8	7.18	8.7
1,5%	2.2	3.0	3.9	4.5	5.21	8.6
2,0%	2.3	2.3	3.0	4.4	6.07	7.8
2,5%	1.5	2.3	2.3	4.3	6.04	6.8

Figure-18: Three-point flexing and compressive strength of NDJA adobes at different days of pulp maturation and for different formulations with the 1.25mm rice husk.



	0 day (flexing)	7 days (flexing)	14 days (flexing)	0 day (compressive)	7 days (compressive)	14 days (compressive)
0,0%	1.8	2.0	2.2	4.6	5.0	5.2
1,0%	2.2	2.4	2.5	4.8	5.9	6.2
1,5%	1.5	2.3	1.8	4.0	5.4	5.3
2,0%	1.5	1.2	1.8	3.6	5.3	5.3
2,5%	1.7	1.7	1.8	4.1	4.8	5.3

Figure-19: Three-point flexing and compressive strength of MOD adobes at different days of pasta maturation and as a function of the percentage of 1.25mm rice husks.

Table-3 shows the strength gains of 1% rice husk known in this study as the optimum percentage compared to 0%. For the NDJA soil, this gain in three-point bending and compression increases with maturation time for the same rice husk rate. The same is true for the compressive strength of the MOD soil, however this gain decreases in bending and then remains constant at days 7 and 14 of maturation.

Table-3: Gain in mechanical strength of 1% adobes as a function of days of maturation.

Origin of clayey soil	Gain in bending strength			Gain in compressive strength		
	0 day	7 days	14 days	0 day	7 days	14 days
N'Djamena	22%	27%	31%	15%	21%	27%
Moundou	27%	14%	14%	12%	18%	20%

Conclusion

This study evaluated the effect of rice husk in clay-based adobes. The percentage of rice husk used varied from 0% to 2.5%. The specimens were made with 0 days, 7 days, 14 days of maturation. The results show that: the water absorption coefficient of adobes decreases with increasing rice husk content and day of maturation of the formulated pastes. The three-point bending strength reaches an optimum value at 1% of rice husk content at different days of curing; the compressive strength is also optimum at 1% of rice husk content at different days of curing. The compressive strength values are better than the flexural strength values. When we use 1% rice husk in clay soils, the gain in mechanical strength is improved by 5% to 6% for a 7-day ripening interval of NDJA soil.

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