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RESEARCH ARTICLE

Characterization of cementitious mortar with addition of fibers from waste paper

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Abstract

As a contribution in resolving some defects frequently encountered in conventional mortars, such as the lack of good flexural strength and cracks propagation, sand was partially substituted by fibers from waste paper in a standardized Portland cement-sand mortar. The weight ratios of sand and paper were: (0/6)S, (1/12)S, (1/6)S, (2/6)S, (3/6)S, (4/6)S, (5/6)S and (6/6)S. Fibers from waste paper used were of two types: One from secretariat paper and the other from newspaper. Tests were performed in fresh and hardened materials. Results at 7 days and 28 days showed that: the incorporation in the mortar of small quantity (1/12)S of fibers from waste paper improved compressive, flexural and tensile strength of mortars. Mortars containing newspaper had better mechanical properties than those containing secretariat papers. The incorporation of fibers from waste paper from (1/6)S to (6/6)S in the mortar increased the initial and final setting time of the cement, reduced the workability of the mortar, the compressive, flexural and tensile properties dropped progressively as the quantity of paper in the mortar increased, considerably solved the problem of shrinkage, decreased the apparent density of the mortar and increased water absorption as the fibers from waste paper increased in the mortar. Immersion of mortars in reactive environments (acetic acid and sodium hydroxide) showed a loss of compressive and tensile strength of the mortar specimens. Given its low weight, low density, good mechanical properties, this new material could be used in the manufacture of lightweight panels not exposed to chemical aggressive environments.

Keywords Reinforced mortar · Cement · Fiber mortar · Waste paper · Physical properties · Mechanical properties

Abbreviations

MIPROMALO	Local materials promotion authorithy
EN	European norm
%W or $\%A_b$	Percentage of water absorption
CIMENCAM	Cameroon cement
ISO	International organization for standardization
CEM	Portland cement
NF	French norm
CPJ	Compounds of Portland cement
CAMWATER	Cameroon water utilities corpporation
W/C	Water–Cement ratio
"S"	Fibers from secretariat paper
"N"	Fibers from newspaper

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1 Introduction

Nowadays, due to the rise of environmental consciousness and awareness of industrial pollution, industries such as building, construction and manufacturing must necessarily ensure production of reliable and environmentally friendly materials [1]. One of the ways of doing so is the reuse of industrial by-products or waste [2–5], as well as the use of natural renewable sources, which are generally considered necessary choices in construction. The replacement of conventional synthetic fibers by natural cellulosic fibers has occupied the attention of researchers, as well [6, 7]. Due to their physical, chemical, and mechanical properties, cellulosic fibers have the potential to be used in the building industry [8, 9], for reinforcing plasters [10]. Cellulosic fibers are widely available and are produced in large quantities and various morphologies (in the form of pulp or short filament fibers), aspect ratios, and sizes across the world. Cellulosic fibers are low-cost in comparison to synthetic fibers, have no known health hazards, have adequate stiffness and strength, are easy to process and recycle, and are eco-friendly [8, 11–13]. The physico-mechanical properties of fiber-cement-based composites depends on the fiber-matrix interactions. The interface controls the strength of composite materials, because stress is transferred from fiber to fiber through the matrix [14]. Many studies have described the behavior of composites cement with agricultural by-products or waste based on ligno/cellulosic nature fibers/aggregates from bamboo [15], hemp hurds [16–18], and coconut [19]. A review of the research results obtained in the last few years in the field of cement-based composites/mortars reinforced with cellulosic fibers focusing on their composition, preparation methods, mechanical properties, and strategies for improving fiber-matrix bonding and composite durability is given in [20]. Cellulosic fibers contribute to the development of high-quality environmentally friendly building materials. Building materials reinforced with fibers are used in a wide range of applications, from building, plastering and mortaring systems to non-load-bearing composites, lightweight panels and decorative applications [21, 22]. Cellulosic fibers obtained from waste paper packaging [11], waste packaging boxes, and papers [7, 16, 23] were used in composites cement. As shown in paper [24], these cement-based composite systems present a tension-softening behavior with low tensile ultimate strength, resulting in products that are more suitable for non-structural applications. The known products manufactured with recycled cellulosic fibers are plasterboard, insulation materials for the thermal insulation of walls and floors, sound insulation of ceilings and roofs, as well as bricks made of waste paper fibers agglomerated with cement [25]. In the field of cement-based plaster mortars based on the recycled cellulosic fibers the low number of literature sources is recorded. As shown in [26], the addition of waste fibers resulted in improved mechanical properties of mortars hardened for 28 days, compared to the control mortar. An increase of 4% was observed in tensile strength on flexural stress, and of 7% in compression strength for the mortar prepared with 1.5% cellulose pulp.

With all the cellulosic fibers mentioned above, cellulosic fibers taken from waste are recommended to preserve the raw materials, ecology and protect the environment. This is why the choice deserves to be made on the waste of paper from secretariats and newspapers which are used a lot and which end as waste in environment after their use. Paper waste from secretariats and newspapers is very rich in cellulosic fibers. The process of obtaining these deserves to be known. Their addition in the cement mortar simply comes to support or supplement the results and assertions of previous work close to this article. In previous work focus the fibers from waste paper were dry before used to the mortar or concrete. But in this article, the wet fibers from waste paper was used. Less attention was given on the use of waste paper from different origin like newspaper waste and secretariat paper waste in literature review. Previous work has not yet shown an improvement in the mechanical properties of mortar with the addition of a small quantity of fiber from newspaper and secretariat paper as shown in this article. The comparison of these two types of papers in the mortar is not yet very well elucidated in previous works. the problem of durability of these mortars must be sufficiently elucidated. The purpose of this paper is to contribute in the improvement of certain defects frequently encountered in conventional mortars by the addition of fibers from waste paper. Investigation constitute of the determination of physical and mechanical properties of a composite mortar made with cement and fibers from waste paper. The objective of the study is to formulate, characterize and determine the properties of lightweight mortars containing paper waste. To achieve this objective, a preparation of the raw materials was carried out. A formulation of the mortar with the addition of fibers from waste paper was then carried out. The influence of fibers from waste paper on the mechanical properties of mortars was evaluated. And finally, recommendations for an efficient recovery of fibers from waste paper in the mortars were prescribed in this study.

2 Materials and methods

The objective here is to have a constant W/C ratio and to gradually replace sand by fibers from waste paper for all dosages. Then the results are compared with a normal reference mortar (control) made according to the same implementation processes.

3 Materials

The materials used are:

- River fine sand 0/5 from Sanaga (Ebebda – Cameroon)
- Cement, CPJ CEM IV/B 22.5R from CIMENCAM (Douala-Cameroon)
- Waste paper coming from secretariat, printing press, newspaper sales kiosk, public and private services.
- Drinking water coming from Camwater-Cameroon.

Grain size analysis: This test is defined by standard NF P18-560 EN 933–2. This test has been widely studied by Dreux Gorisse and Festa [27]. The grain size analysis is carried out after the removal of particles greater than 5 mm and less than 0.02 mm with the passage of sand over the sieves

(5 mm and 0.02 mm). The sand was washed beforehand with a 0.063 mm sieve and dried by the oven.

Preparation of paper pulp: The sheets are detached, the staples are removed, and the coarse papers are cut or torn and soaked in a large quantity of warm water. Ideally, a tube or large bucket reserved for this purpose is recommended. The papers are left to get soft, and after 14 days of soaking, the paper is ready. It forms a kind of thick mush, hence the interest of a very ordinary paper. From time to time, the paper is turned so that it mixes well and makes a homogeneous pulp, then the pulp is wring out, i.e. the water is removed from the pulp, and after wring out the pulp is crumbled using a 5 mm sieve. The same procedure is used for newspaper papers. The paper pulp preparation process is given in Fig. 1 below.

We then obtain the wet fibers of waste paper (secretariat or newspaper). The wet fibers is then stored in a hermetically sealed bucket and kept in a humid room, preferably at a temperature ($t \leq 20$ °C) to prevent any variation in temperature, which could influence the variation of the water content of the fibers of waste paper.

Water content of fibers from waste paper: The water content is measured on the stored fibers from waste paper: The wet mass of the fibers from waste paper is taken and weighed and placed in the oven for 24 h, the dry mass is obtained. M_h = wet mass, m_s = dry mass, w = water content, m_w = mass of water contained in the paper.

$$\%W = \frac{m_h - m_s}{m_h} \times 100 \tag{1}$$

For each wet sample and for each type of paper (secretariat papers and newspapers), the water content is 73.34% for secretariat papers and 76.71% for newspapers. The purpose of determining the water content is to know beforehand the quantity of water contained in the fibers from waste paper before it is added in the mortar. Because this water content in the fibers has made it possible to fix the quantity of water in the mixture in order to have a constant W/C ratio.

3.1 Methods

3.1.1 Physical and chemical characteristic of cement

The cement used is the composed Portland cement CPJ 35 from Cimencam. The Tables 1 and 2 below show the physical and chemical characteristic of cement used, in accordance with Cameroonian standard NC 234: 2009–06:

3.1.2 Physical characteristic of sand river

Figure 2 below shows the curve of the grain size analysis of the river sand used.

The fineness modulus is $M_f = 2.19$, thus the fine sand obtained has a spread out grain size which is within the recommended range for ordinary mortars as demonstrated by Dreux Gorisse and Festa [27]. Since the sand used has been well washed and dried before hand, the sand equivalence is close to 100%. Table 3 below shows the characteristics of the sand used.

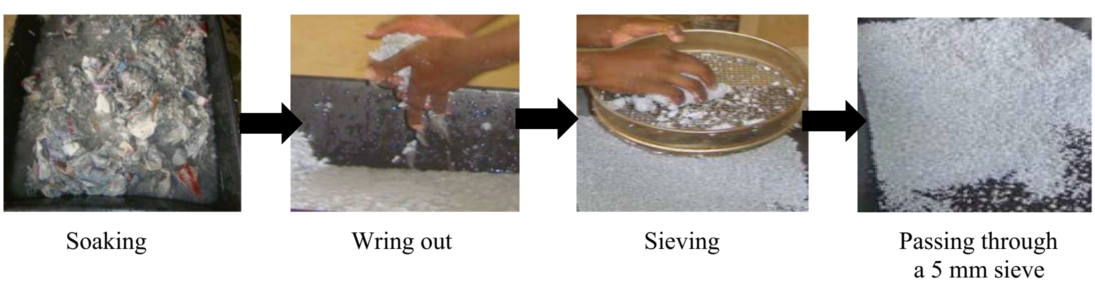

Fig. 1 Paper pulp preparation process

Table 1 Physical characteristic of cement

Material	Nature	Manufacturer	Specification	Standard	Weight (Kg)
Cement CPJ35	Classic	CIMENCAM	CEMIV/B 22.5R	NC 234: 2009–06	50

Table 2 Chemical characteristic of cement [28]

Material	S_iO_3	Al_2O_3	Fe_2O_3	MnO	CaO	Na_2O	K_2O	T_iO_2	P_2O_5	Loss to fire	Pozzolana
Cement CPJ 35	19.5	4.79	2.74	0.04	60.42	0.18	0.93	0.25	0.51	0.02	10

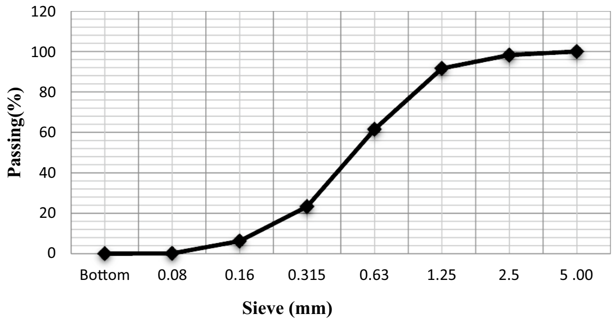

Fig. 2 Granulometric curve of sand used

Table 3 Characteristics of the river sand used

Characteristics	Value
Fineness modulus (M_f)	2.19
Coefficient of Curvature C_c	1.08
Uniformity Coefficient C_u	3.32
Apparent density M_{Vapp} ($Kg.m^{-3}$)	1700
Sand equivalence after washing ESV (%)	≈ 100

3.1.3 Physical and chemical characteristic of paper

The physical and chemical characteristics of waste papers used are presented in Tables 4 and 5 below:

3.2 Composition and preparation of specimens

Dosage of mortars: Normal mortar was made according to EN 196–1. The standard describes the sand used for the tests and the mixer. The sand and cement are mixed with water in the following proportions: 450 g ± 2 g of cement, 1350 g ± 5 g of clean, well-washed sand and 225 g ± 1 g of water. The W/C ratio of this mortar is therefore 0.50.

Table 6 Dosage of paper mortar components

Ratio	Sand ($kg\ m^{-3}$)	Paper ($kg\ m^{-3}$)	Cement ($kg\ m^{-3}$)	Water ($kg\ m^{-3}$)
(0/6)S	1350	0	450	330
(1/12)S	1237.5	112.5	450	330
(1/6)S	1125	225	450	330
(2/6)S	900	450	450	330
(3/6)S	675	675	450	330
(4/6)S	450	900	450	330
(5/6)S	225	1125	450	330
(6/6)S	0	1350	450	330

Several dosages were carried out in order to progressively substitute the sand with paper until 0% sand is reached. The fibers of waste papers were in the following proportions: (0/6)S, (1/12)S, (1/6)S, (2/6)S, (3/6)S, (4/6)S, (5/6) S and (6/6)S of the mass of sand S = 1350 $kg.m^{-3}$. The dosage of cement and water remains constant. The quantity of water stopped depended on the good consistency of each dosage carried out. These operations are recorded in Table 6 below:

According to the requirements of the standard NF EN 196–1, the water was first introduced into the mixer tank; the cement was introduced afterwards, and then the mixer was started at low speed. After 30 s of mixing, the sand was introduced regularly for the next 30 s. Then the mixer was set at high speed for 30 s. Then the mixer was shut down. The rubber squeegee was used to remove all the mortar adhering to the walls and bottom of the mixer by pushing it towards the middle of it. The mixer was switched on again for 15 s before passing the mixing at high speed for 60 s. To make the test specimens, the moulds were first made. According to standard NF EN 196–1, standardized moulds demountable (Fig. 3) are

Table 4 Physical characteristics of papers

Type of paper	Weight (g/m^2) [29]	Dimension of paper used (mm)	Format (ISO-216) [29]	Thickness (micron) [29]	Number of cellulosic fiber ($fibers/mm^3$) [30]
Secretariat paper	70–80	420 × 297 210 × 297	A3 A4	100	≈ 13.745
Newspaper	42–50	575 × 410	A2	70	–

Table 5 Chemical Characteristics of papers [31]

Composition	Moisture (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Lignine (%)	Others (%)
Secretariat paper	3.2	78.6	4.7	1.2	9	1.2	3.3
Newspaper	3	49.3	12.2	19.18	1.5	19.18	4.9

Fig. 3 Prismatic Mould. Mould filling. Mould leveled and labeled

Fig. 4 Mortar specimens

used to produce 3 prismatic test specimens with a square section of 4 cm x 4 cm and a length of 16 cm. These tests specimens are called "4 × 4 × 16" tests specimens. These are the dimensions that were adopted for these tests. The mould is filled with mortar (Fig. 3). The mortar is clamped in moulds introducing it in two layers and applying 60 shocks to the mould each time. The mould is then leveled and labeled (Fig. 3). Three experimental sample specimens have been made for each test and for each dosage.

After 24 h from the start of mixing, these specimens are removed from the mould and stored in a damp cabinet at a relative temperature of ± 20°c. The mortar specimens are in Fig. 4 below.

3.3 Test on fresh and hardened mortar

3.3.1 Test on fresh mortar

Measurement of the initial and final setting time: According to standard EN 196–3, the test consists of following the evolution of the consistency of a paste. A simple paste (normal mortar) is tested and the initial and final time are observed, then a paste with 10% of fibers from waste paper is tested and the initial and final time are observed, then 20% of fibers from waste paper is also tested and the initial and final time are observed.

Workability of mortars: The workability of mortar characterizes its greater or lesser fluidity. The test which makes it possible to assess this consistency is the Abrams Cone slump test or workability test, in accordance with standard NF P 18–451. It consists of 4 elements: a bottomless tapered mold 30 cm high, 20 cm in diameter at the bottom and 10 cm in diameter at the top; a backing plate; a picketing rod; a graduated ruler. The measurement is made and the result makes it possible to make an approximate classification of this mortar.

3.3.2 Test on hardened mortar

For each test on the hardened mortar, 3 prismatic specimens having the same dosage are tested, the result retained is the average obtained on the 3 specimens.

Flexural and compressive strength of specimens: At day 7, then day 28, the specimens are broken in flexion and compression. The test was achieved according to EN 196–1 norm on a machine of 10 KN power and a speed of setting in load 50 N/s. If F_f is the breaking load of the specimen in bending, the corresponding flexural strength on the under side of the specimen is:

$$R_f = \frac{1.5 \times F_f \times 1}{b^3} \tag{2}$$

The compression test on prismatic test-tubes was achieved according to EN P 15–45 norm. The press used was 150 KN power and the speed of setting in load was 2400 N/s. The half-prisms of the test specimen obtained after failure in bending were broken in compression. Fc is the breaking load in compression, the breaking stress was:

$$R_c = \frac{F_c}{b^2} \tag{3}$$

Tensile strength of specimens: According to NF EN 1992-1-1, the tensile strength at "j" days, noted R_t or f_{tj}, is conventionally defined by the relationships:

$$R_t = f_{tj} = 0.6 + 0.06 f_{cj} \quad \textit{if} \quad \mathrm{fc28} > 60\,\mathrm{MPA}, \tag{4}$$

The determination of the tensile strength was derived from the compressive strength using the formula above. R_c or f_{cj} is the compressive strength at "j" days.

Apparent density of the specimens: According to standard NF 12,390–7, after their demoulding, the 3 specimens E_1, E_2, E_3 respectively are measured to determine their volumes, then weighed, the masses m_1, m_2, m_3 are noted. These specimens are placed in an oven for 48 h. After drying, the specimens are weighed again and the dimensions of the specimens are measured again to determine their volumes. The apparent density is then determined by the relationships:

$$\rho_v = \frac{M}{V} \quad (5)$$

3.3.3 Durability test

Shrinkage of the mortar specimens: The shrinkage, caused by the cement studied on normal and paper mortar specimens is evaluated. At different times t, the variation in length of a 4×4×16 specimen is compared with its length at a time taken as the origin. It is described in standard NF P 15–433. A demometer equipped with a comparator enabling measurements to be made with an accuracy of less than or equal to 0.005 mm. The shrinkage tests were carried out on the specimens at day 1, day 7, days 14, and day 28 for normal mortar and mortars containing (1/12)S, (1/6)S and (2/6)S. The relative variation of length is generally denoted by "ε" and has the expression:

$$\varepsilon(t) = \frac{\Delta l(t)}{L} = \frac{dl(t) - dl(t0)}{L} \quad (6)$$

Water absorption of the specimens: According to standard NF EN 1097–6. The test tubes, after being removed from the mould, were placed in an oven for 48 h at a temperature of 60°c, and then weighed, this is the dry mass (m_s), then immersed in water for 24 h and weighed again, and this is the wet mass (m_h). The water absorption rate of the specimen is:

$$\%A_b = \frac{m_h - m_s}{m_s} \times 100 \quad (7)$$

Compressive and tensile strength of specimens in acido-basic medium: At day 28. The mortar specimens (normal mortar and mortars with the addition of (1/12)S of "S" and "N") are immersed for 30 days in two reactive solutions of different types: Water acidified with acetic acid (CH3-CO–OH) with a PH = 4 and in an artificial alkaline medium established from sodium hydroxide (NaOH) with a PH = 12. The compressive strength test was carried out in accordance with standard NF 12,390-3 and 12,390-4. The specimens are loaded until failure and the maximum load reached is recorded. The compressive strength was calculated by the formula (3) above and the tensile strength was determine using the formula (4) above according to the standard NF EN 1992–1-1.

The Table 7 below show the summary of the test performed with standard and the number of specimens used for each type of mortar. CSABM is the compressive strength in acido-basic medium and TSABM is the tensile strength in acido-basic medium.

4 Results and discussion

4.1 Fresh mortar

Initial and final setting time: The Fig. 5 below shows the influence of fibers from waste paper on initial and finial setting time of cement.

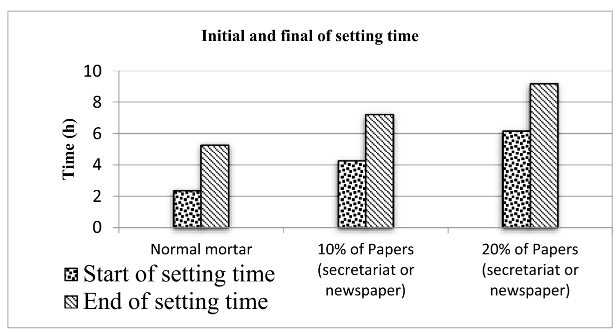

Fig. 5 Influence of fibers from waste paper on the setting time of cement

Table 7 Number of specimens and standard of test on hardened mortar

Test performed	Flexural strength	Compressive strength	Tensile strength	Apparent density	Shrinkage	Water absorption	CSABM	TSABM
Numbe of speciment	3	3		3	3	3	3	3
Total number	24	24		24	12	24	36	36
Standard	EN 196–1	EN P 15–45	NF EN 1992–1-1	NF 12,390–7	NF P 15–433	NF EN 1097–6	NF 12,390–3 and 12,390–4	

Paper waste has a considerable influence on the setting time of cement. A waste paper fiber increases the initial and final setting time of cement. This can be explained by the fact that the cellulosic fibers from waste paper inhibit the hydration of the cement paste, which would increase the initial and final setting time of cement. This confirms the work of simatupang and al who reported that there is a increase in the setting time of cement at partial solubilisation of hemicelluloses during the interaction between cement paste and cellulosic fibers [32, 33]. The results obtained during the measuring of initial and final setting time of mortars with the addition of "S" were similar to those of mortars with the addition of "N".

Workability: Here, the analysis of the fresh mortar as it leaves the mixer has been done. Figure 6 below shows the influence of fibers from waste paper on the workability of the mortar.

The introduction of fibers from waste paper into cement mortars has caused by workability problems. There is a decrease in the workability of the mortar when the percentage of the fibers increases in the mortar. This may be due to the fact that the fibers from waste paper still tend to absorb water in the fresh mortar even after saturation, the appearance of a dry mortar was observed, which allows the mortar to be classified among the firm mortars. Cellulosic fibers have acted as a cement hydration inhibitor, which makes the mortar dry and firm after mixing. The binding of calcium ions on the cellulosic fibers from the waste paper leads to a sharp decrease in these ions in the cement paste. By allowing the fixation of calcium on the fibers from waste paper; pectins inhibit the formation of calcium-silicate gels, which are the major products of the hydration of Portland cement. This has also been demonstrated and proven by several authors like Govin and Sedan [34–36].

4.2 Hardened mortar

Flexural strength of specimens: The tests performed at 7 and 28 days gave the results shown in Figs. 7 and 8 below:

The incorporation of "S" or the "N" in the mortar causes the flexural strength to drop, the strength gradually drops as the "S" or "N" increases in the mix. However, the incorporation of a small quantity of "S" or "N" (1/12)S improves the flexural strength compared to normal mortar. At (1/12)S the fibers play their role of reinforcing the mortar. There is an optimal cellulose content and a good distribution of fibers in the cement matrix which ensures good compressive strength than normal mortar. But beyond (1/12)S there is a problem of good hydration of the cement, the mortar becomes more and more porous which negatively influences the resistance of the mortar. Water is rapidly absorbed by the fibers from waste paper slowing down the action of the cement paste.

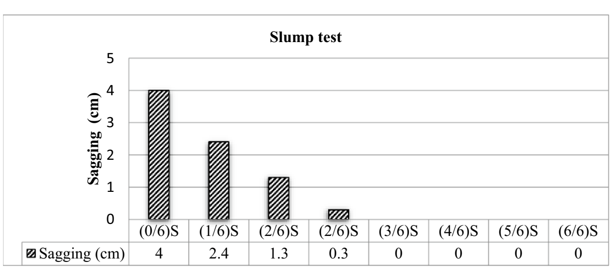

Fig. 6 Influence of fibers of waste paper on workability of mortar (Abrams cone slump)

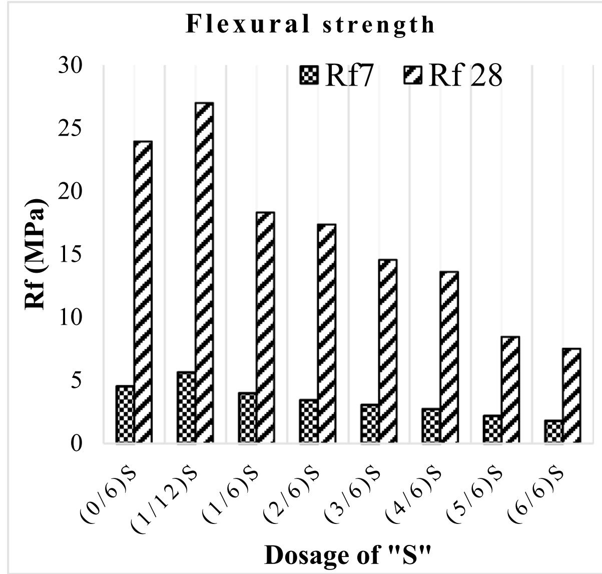

Fig. 7 Flexural strength with respect to the quantity of "S"

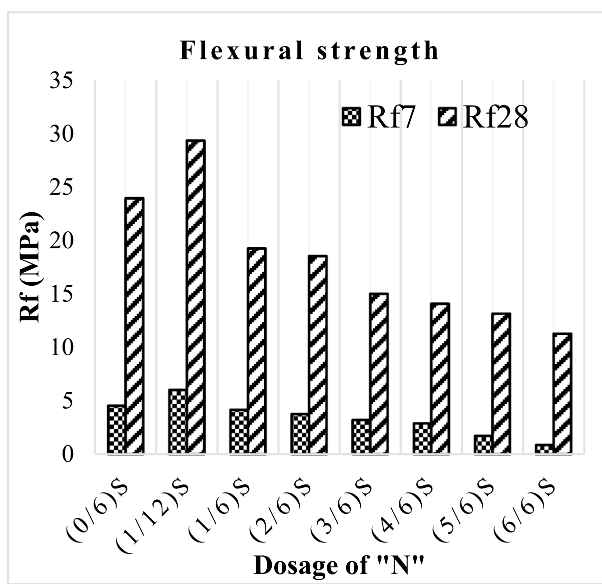

Fig. 8 Flexural strength with respect to the quantity of "N"

Nagraga & Jawaaharlal have had approximate results with the use of bamboo plant fibers [37]. But also the problem of workability observed beyond (1/12)S may be responsible for this drop in resistance.

Compressive strength of specimens: The tests performed at 7 and 28 days gave the results shown in Figs. 9 and 10 below concerning the compressive strength:

The incorporation of "S" or "N" into the mortar decreases the compressive strength and this strength gradually decreases as the waste secretariat paper increases in the mix at 7 days and at 28 days. But the incorporation of a small quantity of fibers from waste paper (1/12)S, slightly improves the compressive strength of the normal mortar. This is contrary to the results of the work of Chafei and Kriker [38, 39] which observes a significant decrease in compressive strength with the incorporation of plant fibers regardless of the percentages of fibers incorporated in the matrix. Most authors state that the compressive strength of fiber-reinforced concrete is generally slightly lower than that of conventional concrete and especially for cellulosic fibers according to Khenfer and Mansur [40, 41]. The reasons why the compressive strength is high at (1/12)S and drops from (1/6)S are similar to the reasons given to explain the flexural strength above.

Tensile strength of specimens: The tests performed at 7 and 28 days gave the results shown in Fig. 11 and Fig. 12 below concerning the tensile strength:

The incorporation of "S" or "N" in the mortar slightly decreases the tensile strength and the tensile strength gradually decreases as the "S" or "N" increases in the mix at 7 days and at 28 days. But the incorporation of a small quantity of "S" or "N" (1/12)S improves the tensile strengt. At (1/12) S of the paper waste, there is an optimal cellulose content and a good distribution of fibers in the cement matrix which ensures good tensile strength than normal mortar, beyond (1/12)S the tensile strength drops. The reasons are also similar to the reasons given to flexural and compressive strength above. Some researchers like Bessadok et al. [42, 43] have shown that this phenomenon depends on the quantity of fiber up to a certain threshold where the effect is reversed as is the case with other types of natural fibers.

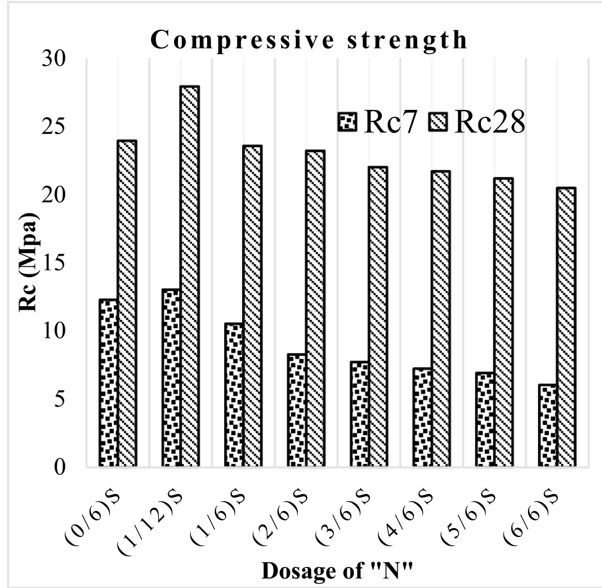

Fig. 10 Compressive strength respect to the quantity of "N"

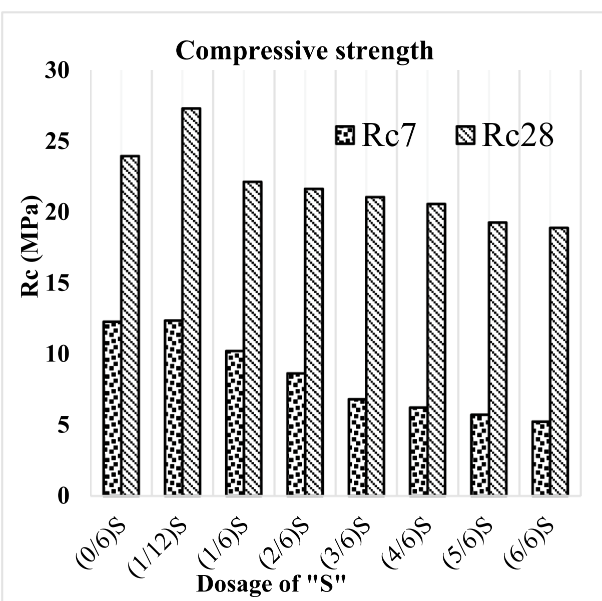

Fig. 9 Compressive strength respect to the quantity of "S"

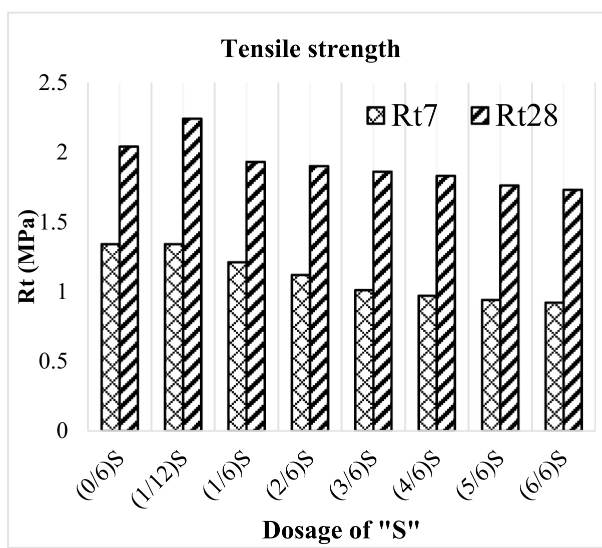

Fig. 11 Tensile strength with respect to the quantity of "S"

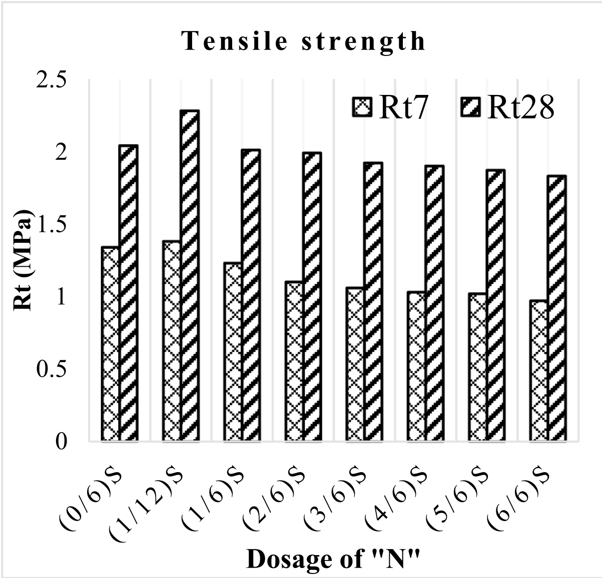

Fig. 12 Tensile strength the quantity of "N"with respect to

Comparison of strengths between secretariat and newspapers: The test performed at 28-day of the specimens for both types of paper gave the results shown in Fig. 13 below concerning the flexural, compressive and tensile strength:

At 28 days, the specimens containing waste newspaper have higher flexural, compressive and tensile strength than those containing waste secretariat paper, regardless of the quantity of paper in the mortar. This may be due to the fact that newspaper waste is better distributed and arranged in the mortar than secretariat paper waste. This is in agreement with the findings of Nagraga and Jawaaharlal [37] who reported that the good distribution of cellulosic fibers improves the mechanical properties. The hemicellulose and lignin fibers contained in waste paper being more numerous in waste newspapers than in waste secretariat papers [31], it could be that this contributed to the improvement of the flexural strength of mortars with the addition of "N". Another reason can be attributed to the higher apparent density of mortars containing the "N" compared to mortars contening the "S". Isaac et al. [43] also thought that the higher apparent density can improve the mechanical strength of mortar with "N" addition compared to mortar with "S" addition.

Apparent density of the specimens: The apparent density was used to explain the behaviour of the mortar in terms of mechanical resistance. Figures 14 and 15 below present the results obtained on the influence of paper waste on the apparent density of the specimens.

From the results obtained, the apparent density after steaming of a control mortar is about 1690.00 kg.m^{-3}. The apparent density decreases as the paper waste increases in the mortar. The apparent densities of the secretariat paper waste are very close to those of the newspaper waste. This may be due to the fact that the nature and composition of secretariat paper is very similar to that of newspaper. Since fibers from waste paper are lighter in weight than sand, it is obvious that replacing sand with fibers from waste papers would lower the apparent density of the test specimens. Jonathan page notes a linear relationship between the porosity of concrete and the apparent density. According to him, the increase in porosity leads to a decrease in density of concrete [44].

4.3 Durability

Shrinkage of mortar specimens: Fig. 16 below shows the results obtained on the influence of paper waste on the shrinkage of the specimens, as the percentage of paper increases, the shrinkage of the specimen decreases.

Paper waste considerably reduces the effects of shrinkage; the shrinkage of the specimens increases with the age of the mortar. The shrinkage of mortar which is caused by the loss of water during drying is partly prevented by the waste paper fibers. Several studies like Batra et al. [45] have concluded that the addition of fibers of all types, including plant fibers, is beneficial for reducing concrete shrinkage. This reduction is affected by several parameters such as: The drying time and the quantity of fibers. If the shrinkage stresses decrease as the percentage of paper increases, this simply means that there is a reduced risk of cracking in the mortar or concrete.

Water absorption of the specimens: Figs. 17 and 18 below show the results obtained on the influence of fibers from waste paper on the water absorption rate of prismatic specimens after steaming and immersion in water for 24 h:

From the results obtained on the different mixes in Figs. 17 and 18 above, the water absorption of a normal mortar can be observed (0% paper waste) is lower than that of the mortar containing paper waste, i.e. the water absorption increases when the paper waste increases in the mortar. This phenomenon can be explained by the fact that fibers from waste paper are porous materials. This can also be explained by the fact that the water absorption coefficient of cellulosic fibers is very high. Most of them can absorb a mass of water greater than their own mass. This has also been observed by Jonathan [44, 46].

Compressive strength of mortars in acido-basic environment: Figures 19 and 20 comparatively show the compressive and tensile strength as a function of the nature of the solution used.

The results obtained shows that the mechanical compressive and tensile strengths of (1/12)S test pieces of "S" and "N" that have remained for 28 days in acidic media and basic media on the other hand are practically similar. The nature of the solution doesn't have too much influence on the compressive and tensile strength of the specimens. There is nevertheless a loss of compressive and tensile strength of the mortar specimens.

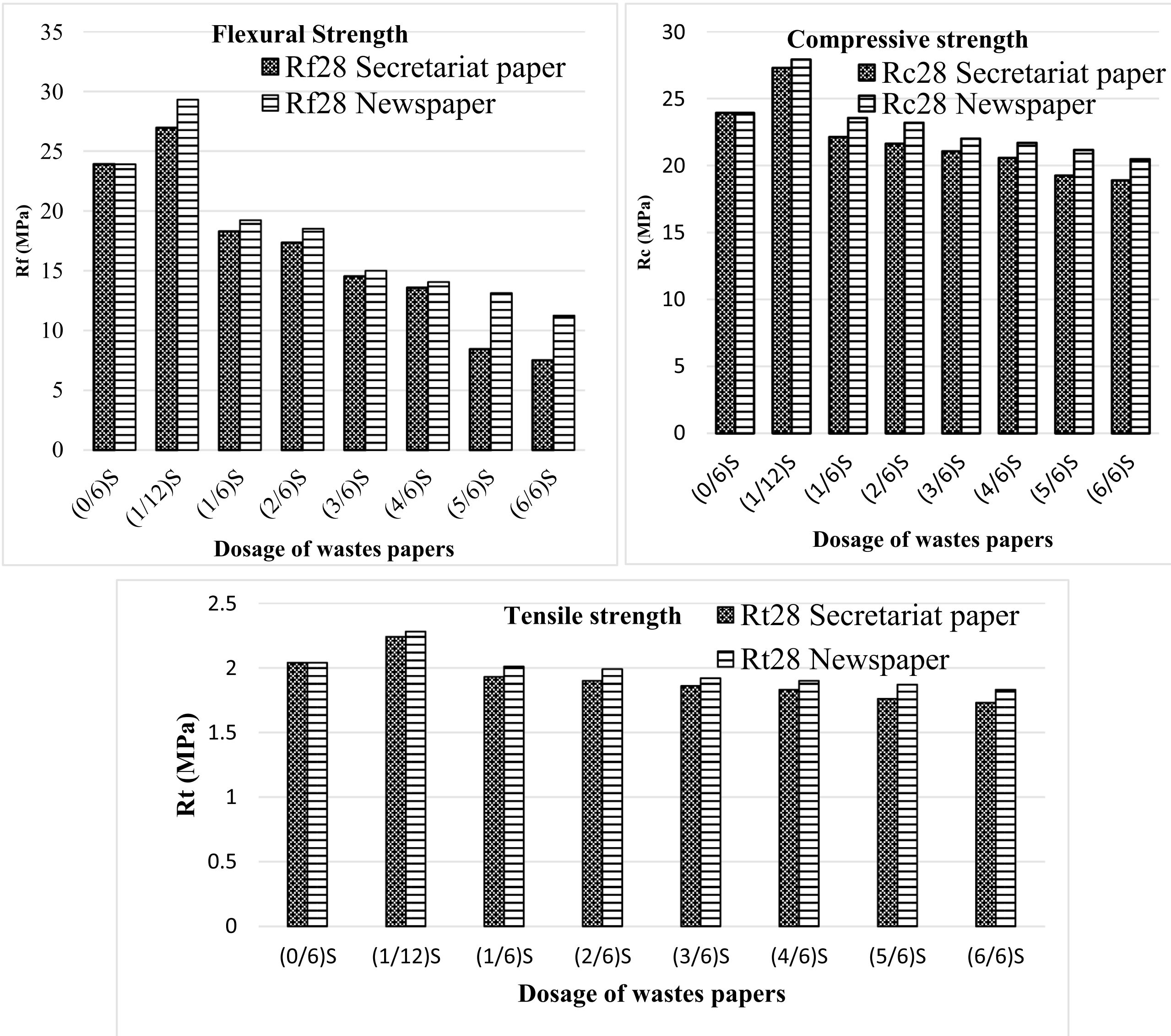

Fig. 13 Comparison of the histogram of the 28-days flexural, compressive and tensile strengths of the specimens for the two types of paper used

This difference can be attributed to crystallization in the pores of the fibers immersed in the sodium hydroxide solution, which affects their tensile strength. These results obtained are also similar to the results obtained by Dounya Chahidi and al [47, 48]. But this is in contradiction with Toledo and al [49] who reported that, the immersion of a solution of (NaOH) for 420 days significantly increases the residual resistances compared to the initial resistance.

5 Conclusion

At the end of this study the following conclusions can be drawn: (1) the incorporation of fibers from waste paper in the mortar formulation causes a considerable drop in the workability of the mortar. (2) Increases the initial and final setting time of the cement. (3) Considerably solves the problem of shrinkage and therefore cracking, decreases the apparent density, increases the rate of water absorption, (4) The flexural, compressive and tensile strength improves with the incorporation of a small quantity of fibers from waste paper (1/12)S compared to standard mortar. (5) The incorporation of (1/6)S of fibers from waste paper, the flexural, compressive and tensile strength starts to drop until it is below that of the normal mortar. (6) The immersion of mortars in acido-basic environments shows a loss of compressive and tensile strength of the mortar specimens. (7) The waste newspaper has better mechanical properties than waste secretariat paper as has been observed. The decreases in mechanical strength

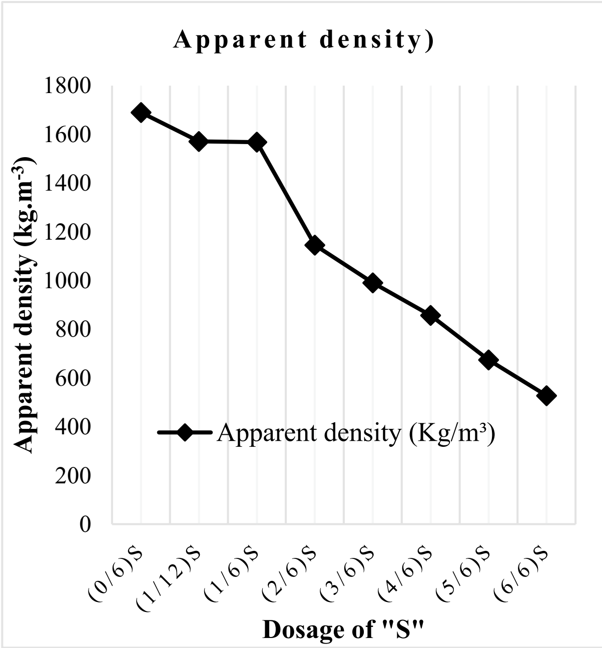

Fig. 14 Influence of "S" on the apparent density of the specimens

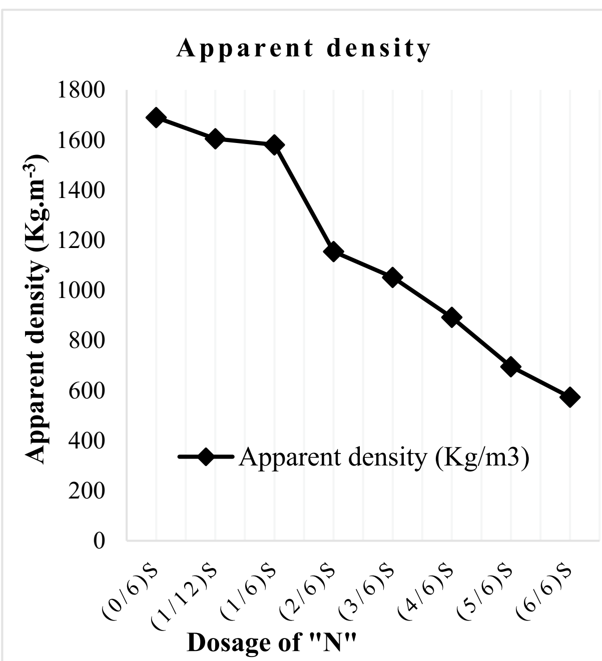

Fig. 15 Influence of "N" on the apparent density of the specimens

when adding waste paper fibers in this study was similar to observations made by other authors [50, 51], but the improvement in strength observed with the addition of a small proportion of waste paper fibers of paper (1/12)S is a particulary of this work. This result means that we have an even lighter material that can easily be used for

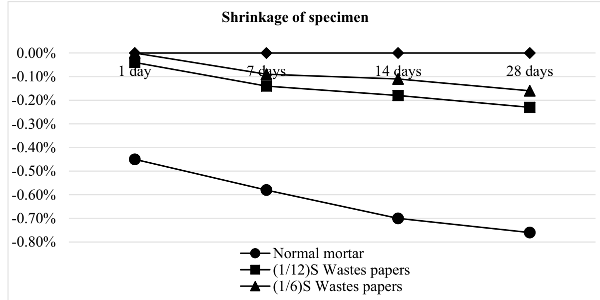

Fig. 16 Influence of paper waste on specimen shrinkage

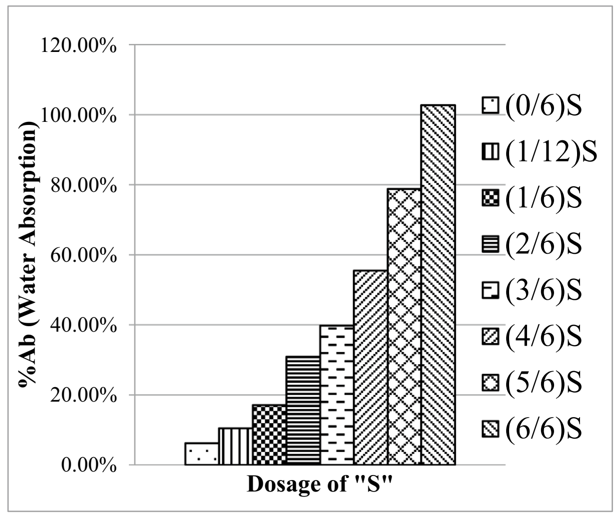

Fig. 17 Influence of "S" on the rate of water absorption of the specimens

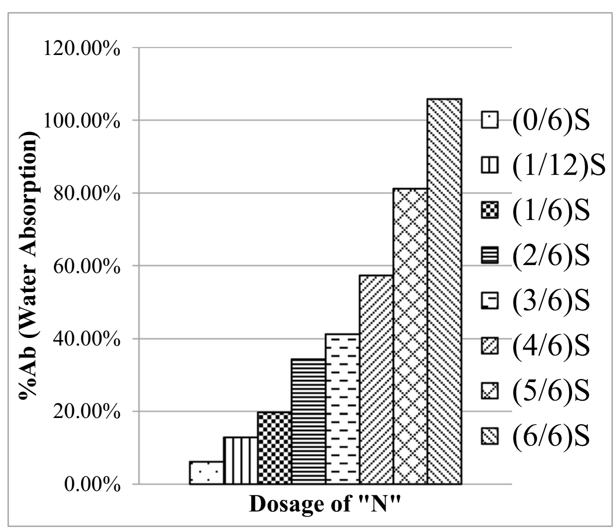

Fig. 18 Influence of "N" on the rate of water absorption rate of the test tubes

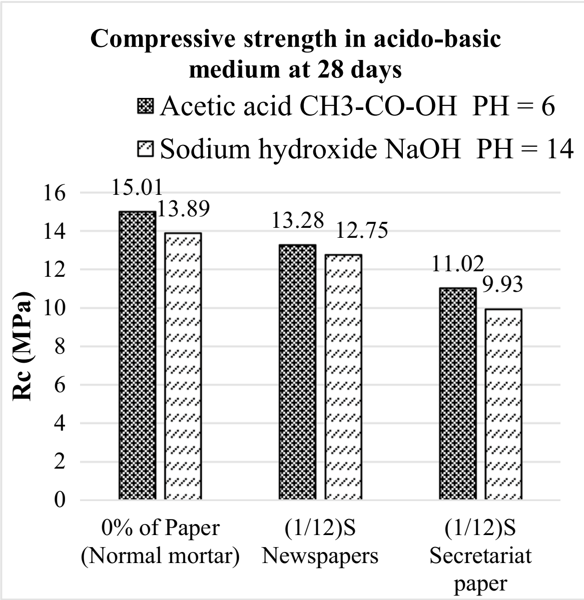

Fig. 19 Compressive strength in acido-basic medium at 28 days

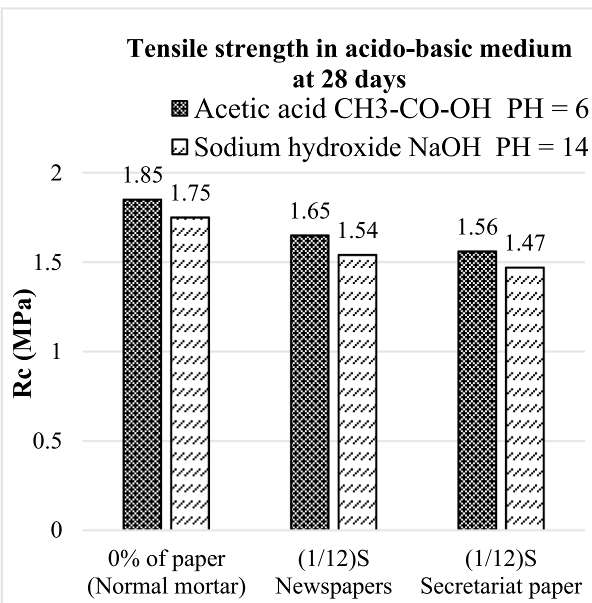

Fig. 20 Tensile Strength in acido-basic medium at 28 days

the manufacture of mortars and lightweight concrete for panels. The use of this new material in the manufacture of thinner elements such as lightweight wall and especially ceiling panels could be satisfactory.

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Author contributions KNA initiated the project and realized it with NB. CHB and YE read and approved the final manuscript.

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Declarations

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