Moroccan Journal of Chemistry
ISSN: 2351-812X
http://revues.imist.ma/?journal=morjchem&page=login
Y. Hmidani & al. / Mor. J. Chem. 9 N°4 (2021) 857-875

Improvement of the mechanical and thermal properties of concrete based on lightened aggregates

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Received 15 Nov 2021,
Revised 15 Dec 2021,
Accepted 19 Dec 2021

Abstract

The objective of this work revolves around the search for a new lightweight concrete formula based on new natural raw materials and waste building materials. This concrete must have acceptable thermal properties while maintaining the mechanical properties used in buildings. In this work, experimental studies were carried out in order to characterize the mechanical and thermal properties of several concrete dosages. The results of this study highlight the possibility of manufacturing a light concrete mixture with a density ranging from 1600 to 1950 Kg/m^3. This new concrete has insulating properties equivalent to those of silico-limestone bricks, hollow cement agglomerates and cavernous concretes, the thermal conductivity relative to the formulas of light concretes with the desired mechanical strengths ranges from 0.82 to 1.05 W/mK. It should be noted that concrete commonly used in building work is characterized by a thermal conductivity of 1.65 to 2.00 W/mK depending on the density of the concrete [1]. The compressive strength on cylinder of -all concrete formulas-, is endowed with a low quality with a value ≥ 12 MPa to correct with 32MPa depending on the type and the dosage of cement used, either CPJ 45 or CPJ55 without exceeding 500 kg/m^3.

Keywords: *New lightweight concrete formula; Natural aggregates; Mechanical proprieties; Thermal proprieties; High Performance Concrete.*

1. Introduction

Concrete is the most widely used building material in the world, with different types being invented to meet the purposes of its use. This explains why several performances are still under development today, and among them, mechanical and thermal performance.

Improving the thermal performance of the building materials helps to strengthen the thermal and reduce energy consumption. Ordinary concrete is one of the most widely used materials in the building compared to concrete based on lightweight aggregates. However, the latter contain satisfactory thermal performance, this is justified by the high porosity factor (microstructure of concretes), however, the decrease in density spontaneously leads to a drop in mechanical strength [2]. The variety of types of light aggregates used in concrete makes it possible to obtain a wide range of densities and mechanical and thermal resistances. Some researchers have worked on the use of solid industrial waste and wood aggregates [3-5], others have focused on the addition of artificial aggregates [6-8], finally, some authors have examined the influence of the substitution of natural aggregates by brick waste on the mechanical behavior of concrete [9, 10].

On the other hand, the sustainability emerged as an indispensable factor in concrete industry, many researchers' targeted micro sized mineral admixtures like as silica fume, fly ash, rice husk ash, slag and so on in order to replace Portland cement which is known to be responsible for almost 7 % of carbon dioxide emission into atmosphere [11, 12].

In the same context, some authors added some products to concrete in order to protect the steel bar in concrete contaminated with chlorides without any adverse effect on the structure [13-17].

This work revolves around the search for a new lightweight concrete based on travertine and terracotta brick debris, characterized by acceptable thermal properties while keeping the stressed mechanical properties corresponding to class C25/30 [18]. As part of this experimental approach, which consists in studying the effect of these additions on the mechanical and thermal properties of concrete, formulas of up to 31 assays were carried out according to the Dreux method by varying the type and dosage of cement and aggregates [19]. Among the advantages of this new concrete are the ease of implementation with a smooth siding like a common concrete, and the possibility of applying surface layers of coating without reducing thermal performance by filling pores and voids as in the case of cavernous concretes. This concrete can be used in the building as a load-bearing material. It is also possible to reduce the dosage of cement and secondary aggregates, if we want to reduce the thermal conductivity below 0.82 W/mK, to use it as a separation material.

2. Experimental program

2.1. Materials :

2.1.1. Constituents of the different concrete dosages:

The different constituents for the manufacture of light concretes are:

- Portland Cement compound CPJ 45 and 55 classes 42.5 N and 52.5 N ;
- Crushed Travertine from the region of Sefrou (T1) and Chefchaouen (T2), its nature consists mainly of calcite ($CaCO_3$). The travertine aggregates used are part of the carbonate rocks that are qualified as non-reactive. Indeed, their total active silica content is less than 4 % relative to the risk of alkali-reaction (Recommendations LCPC 1994 and P18-542) [20].

- ***Travertine aggregates***

1: Travertine substrate
2: Manual crushing
3: sand + travertine gravel.

Photo 1. Method of preparation of travertine

- crushed terracotta brick (BC) waste from the Al Hoceima region, these bricks are durable materials of low water reaction, made from a simple process and using abundant raw materials (clay, sand, ...and water) [21].

- *Crushed brick waste aggregates*

1: Manual crushing.
2: Slight grinding by friction.
3: Washing.
4: Drying.
N.B: The purpose of light grinding is to obtain aggregates with smooth angles and easy to implement without damaging the user

Photo 2. Method of preparation of brick waste

- secondary aggregates such as sea sand (SM) and river sand (SR) to correct the modulus of fineness, workability and mechanical strength if necessary;
- drinking water is used directly without control as wasting water according to SN EN 1008. [22]

2.1.2. Composition (in Kg) of one cubic meter of concrete:

All concrete dosages are carried out on the basis of the Dreux formulation study [19]. It is important to note the problems with the maneuverability of travertine-based concrete from the large amount of water introduced during the manufacture of our concrete. The high porosity and degree of absorption of aggregates nevertheless depends on the interconnection of pores at the aggregate level, the water/cement ratio and the degree of water saturation of the aggregates, knowing that the water absorbed by the aggregates constitutes a reserve for the subsequent hydration of the cementations' matrix [23-25]. As a first step, to correct this problem of water consumption of the waste, travertine aggregates are treated with bitumen by hot way to pack them in an in-absorbent layer. Water consumption has thus been minimized; however, in return, the cost of concrete has increased. In a second step, we changed the steps of concrete manufacturing, leaving the addition of travertine aggregates slightly wet after mixing the concrete matrix (sand, cement and water) to avoid the decrease in the spoiling water necessary for the hydration of the cement. Table 1 below shows the different dosages of concrete with the desired mechanical characteristics.

Table 1. The dosages of references having the desired mechanical characteristics

References and Dosages	Ech 20 (Kg) R1/CPJ55/500	Ech 23 (Kg) R2/CPJ55/500	Ech 30 (Kg) R7/CPJ55/450	Ech 31 (Kg) R8/CPJ55/450
CPJ Cement 55	500	500	450	450
Travertine aggregates (T2)	834	834	_	_
Travertine sand (ST2)	648	676	_	_
Aggregates of brick waste (BC)	_	_	1037	1037
Fine brick waste (FBC)	_	_	613	_
Sea sand (SM)	29	_	_	547
Water	280	290	262	252

2.2. Experimental methods

2.2.1. The characteristic properties of aggregates:

To classify the aggregates used in this study, morphological properties were determined according to French standards; the results are presented in Table 3-2.

We also defined the mechanical properties of the aggregates by calculating the fragmentation resistance according to the NF P 18-573 [26] standard using the Los Angeles machine, as well as by measuring wear resistance according to standard NF P 18-572 [27] using the Micro-Deval machine.

2.2.2. Mineralogical analysis of samples by X-ray diffraction:

The recording of the RX diagrams was carried out using a Shimadzu 6100 type device equipped with a copper anticathode ($\lambda_{Cu}K_{\alpha}$ = 1,541838 Å). The analytical conditions are 40 kV, 30 mA, Ni filter; angular range 10 to 70° 2θ with a scan speed of 0.02° s^{-1}. The identification of the mineral phases in the powder samples was carried out by comparing the RX diagrams obtained with those of the ICDD database (International Center for Diffraction Data).

2.2.3. Measurements of the mechanical properties of concrete:

The mechanical properties of the concrete were evaluated according to non-destructive methods using the Punditlab brand sonic auscultation apparatus according to NF P 18-418 [28], and the dynamic auscultation apparatus using the sclerometer according to standard NF P 18-417 [29]. The results by the sonic auscultation method were evaluated by direct transparency on the cylindrical and/or cubic concrete specimens after 28 days and horizontally or vertically from top to bottom (typing direction) by the dynamic auscultation method. [30].

For destructive methods, measurements were made on cylindrical samples 67/134 mm respecting the form d/h with h =2d, the diameter of the concrete specimen is much larger, three times the diameter of the largest aggregate used. The ramp-up speed is between 0.7 and 3.5 (kN/s)[31]. The compressive strength according to standard NF P 18-406 [32] and tensile strength by splitting according to standard NF P 18-408 [33] are measured by the average of three identical samples for each formulation after 28 days using a hydraulic press.

2.2.4. Measurement of the thermal properties of concrete:

The analyses used to characterize the thermal properties of concrete are:

- thermal analysis by ATG and ATD

Thermal analysis on fine powders of concrete samples or aggregates is carried out under oxygen atmosphere (flow rate 40 mL/min) and ambient temperature up to 1000 °C following a heating rate of 20 °C/min. The device used corresponds to a simultaneous ATG/ATD analyzer brand SETARAM LabsysTMEvo (1F).

- measurement of conductivity, diffusivity and thermal effusivity.

The tests shall be carried out on cylindrical specimens of dry concrete (after 28 days), 67 mm in diameter and 50 mm thick, using the source technique of the transient plane (TPS) or the Hot-disk method at room temperature and normal pressure [34, 35]. The sensor or probe in the form of a double screen-printed Nickel spiral is sandwiched between two identical concrete samples to determine the temperature variation (ΔT). They are calculated by an iterative process to obtain a linear evolution of (ΔT). [36]

3. Results and discussion

3.1. Characteristics of the aggregates:

The characteristics of the base aggregates are given in the table below.

Interpretation of results:

Table 2 shows that the Travertine aggregates, either T1 or T2, are characterized by the same morphological properties (% fine, granular class, particle size nature and density) and the same calcimetry (% $CaCO_3$). The difference lies in the mechanical properties (resistance to fragmentation and wear) as well as in the absolute density. The sands of this travertine are similar however; they have percentages of fine elements, modulus of fineness and sand equivalent. This is explained by the fact that travertine T1 demonstrates a low mechanical strength; in addition, during crushing it

gives a percentage of fine particles, higher than that of T2 and subsequently a low modulus of fineness and sand equivalent.

It should also be noted that the percentage of $CaCO_3$ in travertine sands is lower than in aggregates, since travertine substrates contain voids and pores often filled with clay or other impurities that mix with sands during manual crushing, which decreases the level of $CaCO_3$ at the sand level in percentage terms. Crushed brick waste (BC) contains a percentage of ends, negligible following the method of preparation by washing, the granular class of BC is reduced compared to travertine, however, and they contain acceptable mechanical strength.

Table 2. Results of identification tests on aggregate samples.

Characteristics	Crushed travertine (T1) (Sefrou)	Crushed travertine (T2) (Chefchaouen)	Crushed brick waste (BC)	Travertine sand (ST1)	Travertine sand (ST2)	Fine brick waste (FBC)
- Granular class D/d (NF P18-560) [37]	**20/3.15**	**20/4**	**12.5/1**	**4/0.08**	**4/0.08**	
-% of fine	**0.32**	**0.39**	**0.05**	**18.07**	**12.66**	
-Finesse module	_	_	_	**3.27**	**2.54**	
-Nature of particle size			**continuous**			
-Superficial cleanliness (%) (NF 18-591)[38]	**2.41**	**1.34**	**2.45**	_	_	
-Sand equivalent (NF 18-598) [39]	_	_	_	**69**	**71**	**crushed**
-Apparent density (t/m^3)	**0.82**	**0.80**	**1.08**	**1.09**	**1.10**	
-Absolute density (t/m^3)	**2.18**	**2.31**	**2.31**	**2.26**	**2.48**	
-% of CaCO3 NF P 94-048 [40]	**90**	**93**	_	**79**	**88**	
-Resistance to fragmentation (LA) NF P 18-573 [26]	**61**	**53**	**21**	_	_	
-Wear resistance (CMD) NF P 18-572 [27]	**74**	**69**	**22**	_	_	

- Particle size analysis:

According to the particle size curves of the concrete constituents according to the NP P 18-560 standard of Figure 1, sands are generally poor in fine elements except sea sand (SM). On the other hand, it is low in large elements, travertine aggregates T1 and T2 as well as crushed brick waste (BC) are part of the class of gravel with tight and continuous granularity. The different concrete references are reported in Table 3.

3.2. Characterization of the different types of concrete.

3.2.1. Density of the different concrete dosages at 105 ° C and 20 ° C:

According to the figure 2 above, the density of the different concrete formulas (from 1600 to 1950 Kg/m^3) is measured according to standard NF EN 12390-7 [41]. These formulae are classified LC1.6, LC1.8 and LC 2.1 according to the new version of EN 206. The figure highlights a significant mass gain compared to common concrete of 500 to 1000 kg/m^3 for travertine-based

concrete and 350 kg to 820 kg/m^3 for brick-based concrete. Concrete assays that contain travertine aggregates and its sands retain moisture more than those corrected by sea sand, river sand or containing brick waste.

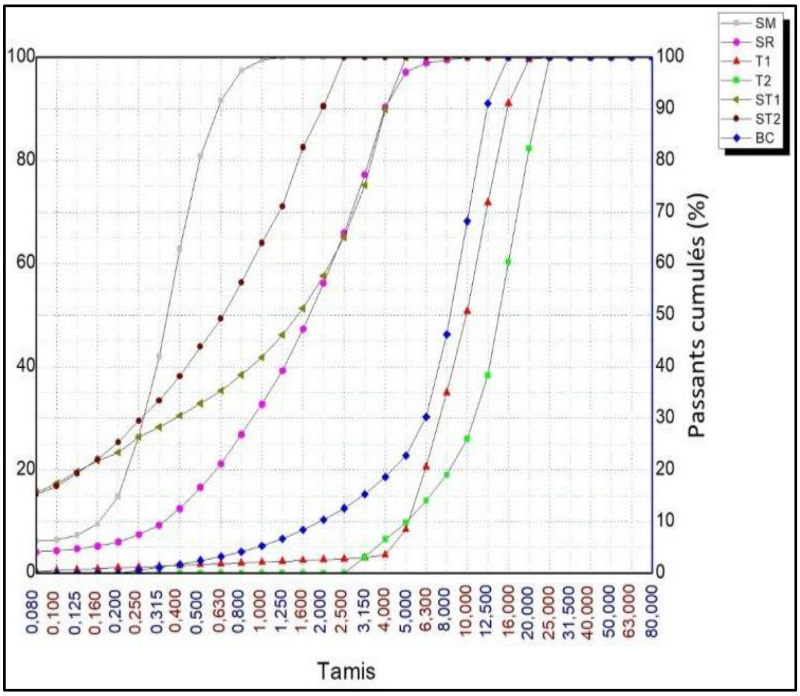
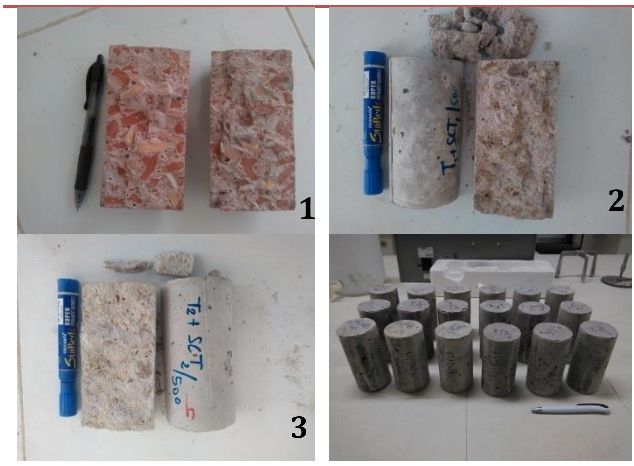


Figure 1. Aggregate particle size curve.

Table 3. References of the different concrete dosages.

Ref.	Basic constituent.	Ref.	Basic constituent.
R1/CPJ45/350	T1+ST1 (Ech1)	**R8/CPJ55/400**	T1+ST1+SM (Ech17)
R2/CPJ45/350	T1+SM+SR (Ech2)	**R9/CPJ55/400**	T1+BC+ST1 (Ech18)
R3/CPJ45/350	T2+ST2 (Ech3)	**R10/CPJ55/400**	T1+BC+SM+SR (Ech19)
R4/CPJ45/350	T2*+ST2 (Ech4)	**R1/CPJ55/500**	T2+ST2+SM (Ech20)
R5/CPJ45/350	T1+BC+SM+SR (Ech5)	**R1/CPJ55/450**	T2+SM (Ech21)
R6/CPJ45/350	BC+SM+SR (Ech6)	**R2/CPJ55/450**	T2+ST2+BC (Ech22)
R7/CPJ45/350	T1*+ST1 (Ech7)	**R2/CPJ55/500**	T2+ST2 (Ech23)
R1/CPJ55/350	T2+ST2 (Ech8)	**R3/CPJ55/450**	T1+ST1+BC (Ech24)
R1/CPJ55/400	T2+ST2 (Ech9)	**R3/CPJ55/500**	T1+ST1+SM (Ech25)
R2/CPJ55/400	T2+ST2+SM (Ech10)	**R4/CPJ55/500**	T1+ST1 (Ech26)
R3/CPJ55/400	T2+SM+SR (Ech11)	**R4/CPJ55/450**	T1+SM (Ech27)
R4/CPJ55/400	T2+BC+ST2 (Ech12)	**R5/CPJ55/450**	T1+ST1+SM (Ech28)
R5/CPJ55/400	T2+SM+SR+BC (Ech13)	**R6/CPJ55/450**	T2+ST2+SM (Ech29)
R2/CPJ55/350	T1+ST1 (Ech14)	**R7/CPJ55/450**	BC+SBC (Ech30)
R6/CPJ55/400	T1+ST1 (Ech15)	**R8/CPJ55/450**	BC+SM (Ech31)
R7/CPJ55/400	T1+SM+SR (Ech16)		

With: T1 (travertine from Sefrou), ST1 (travertine sand from Sefrou), T2 (travertine from Chefchaouen), ST2 (travertine sand from Chefchaouen), BC (crushed brick waste), SBC (Fine crushed brick waste, SM (sea sand) and SR (river sand), the type and dosage of cement are noted in the references. (travertine treated with bitumen)*



1: Fine and aggregates of brick waste.
2: Sand and travertine aggregates T1 from Sefrou.
3: Sand and travertine aggregates T1 from Chefchaouen.

Photo 3*. Example of concrete samples based on lightened aggregates.*

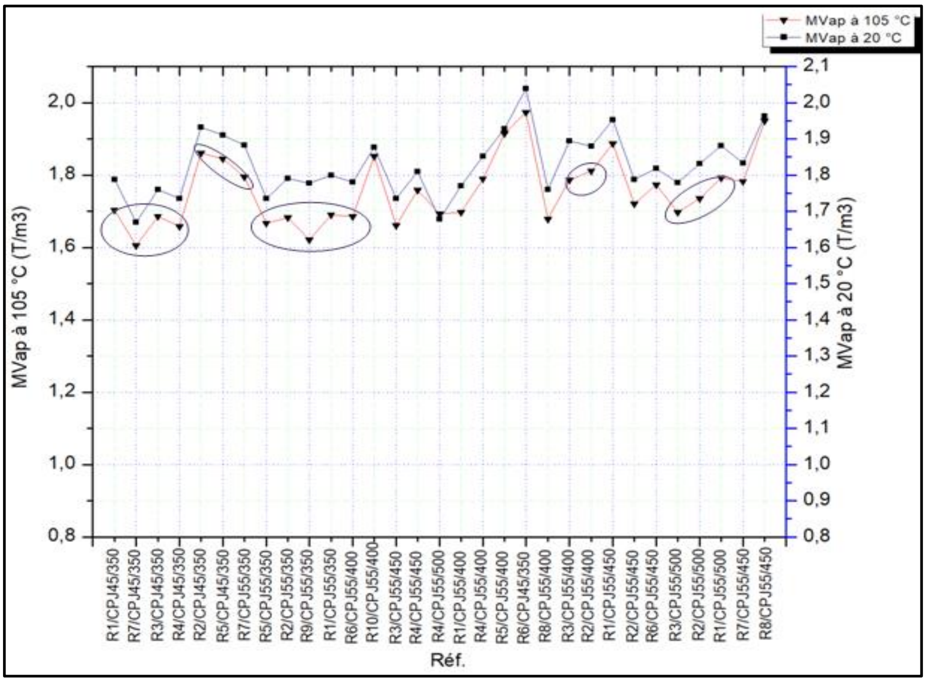


Figure 2. Density of different concrete dosages at 105 °C and 20 °C

3.2.2. Mechanical compressive strength on concrete cylinder:

The above curve of Figure 3, shows that the compressive strength of concretes has a quality ranging from very poor to correct (from 10 to 32 MPa) depending on the type and dosage of cement used either CPJ 45 or CPJ55 without exceeding 500 kg/m^3. The desired mechanical strength of 25 Mpa on cylinder is fixed at the following references:

R2/CPJ55/500 contains T2 travertine aggregates with its crushing sand, the CPJ55 cement dosage is 500kg/m3, its mechanical strength is of the order of 25 Mpa with a density of 1.73 T/m^3.

R1/CPJ55/500 has the same cement dosage as the previous one, corrected with sea sand, the mechanical strength is of the order of 26 Mpa with a density of 1.79 T/m

R7/CPJ55/450 contains crushed and crushed brick waste with a dosage of 450 Kg/m^3 of CPJ55 cement, the mechanical strength is of the order of 29 Mpa and the density is 1.78 T/m^3.

R8/CPJ55/450 contains waste bricks and sea sand with a dosage of 450 kg/m^3 of CPJ55 cement, the mechanical strength is 32.5 Mpa and the density is equivalent to 1.95 T/m^3.

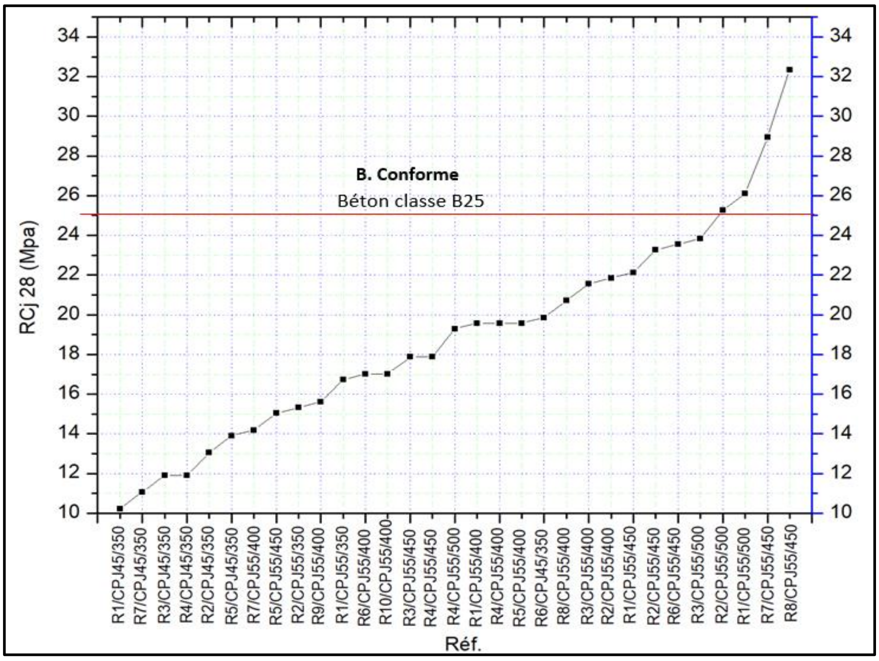


Figure 3. Mechanical resistance on cylinder of the different concrete dosages.

The difference in mechanical strength between two similar dosages of concrete based on travertine aggregates comes in particular from the difference in the resistance to fragmentation of the aggregates.

3.2.3. Ratio of mechanical compressive strength to tensile strength by splitting.

On the basis of the results obtained in the Figure 4, it should be noted that for the majority of concrete formulas, the tensile strength is proportional to the compressive strength. The tensile strength by splitting is between 1.5 and 3.5 MPa. The dosages showing a low tensile strength are those based on Sefrou travertine and its sand, the latter are characterized in fact, by a high percentage of fines (% < 80µm). However, the increase of fine elements in concrete can make it difficult to adhere between cement and travertine aggregates, which cause a drop in tensile strength.

Applying the method of RILEM (1996), the qualitative classifications according to the wave propagation rate for concretes dosed at 350 kg/m^3 of CPJ45 cement, are equipped with a mechanical quality of low to high strength (2,87 à 3,79 km/s) and medium to high strength (3.23 to 4.18 km/s) for concrete dosed from 350 to 500 kg/m^3 of CPJ55 cement. The wave propagation speed is converted to mechanical strength from the resistance estimation curve according to RILEM and the sclerometric indices are converted into mechanical strength according to the calibration abacus of the apparatus, the results are shown in Figure 3-5.

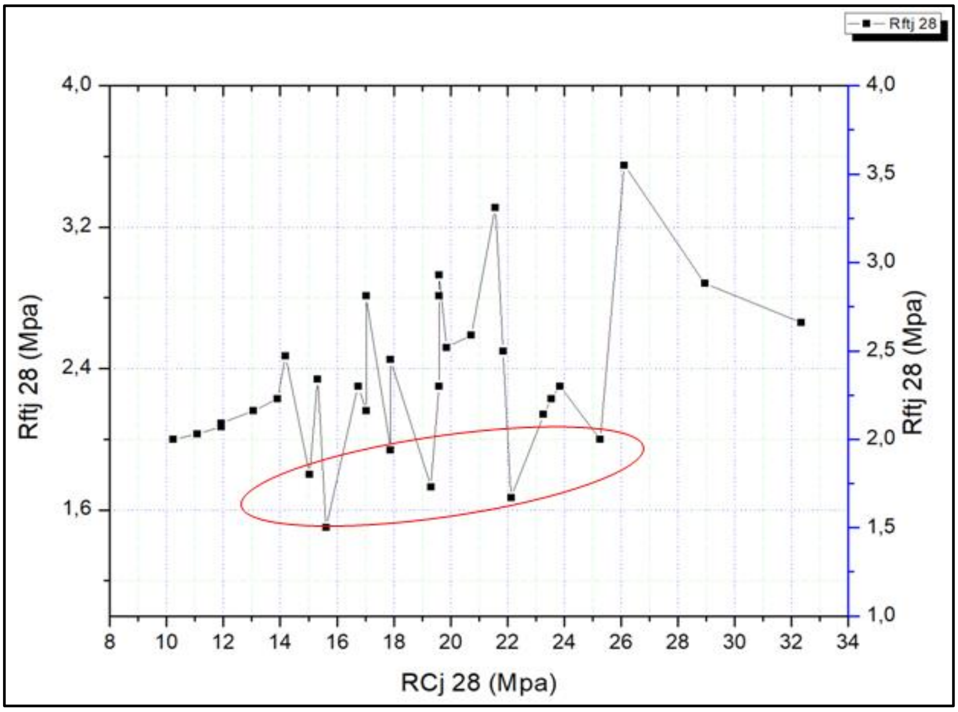


Figure 4. Ratio of mechanical compressive and tensile strength by splitting.

3.2.4. Dynamic and sonic auscultation tests.

The results of the Figure 5, show that the mechanical qualities of non-destructive measuring devices are inferior to those measured by destructive methods. This discrepancy shows that the nature of the aggregates influences the measurements by non-destructive method. This difference is explained by the principle on which each method is based, in fact, the porous nature of travertine aggregates increases the propagation time of the waves between the transmitter and the receiver of the sonic ausculturist, which results in a drop in mechanical performance compared to destructive results. In addition, the low mechanical strength of travertine makes the contact surface less hard during the dynamic auscultation test, thus causing a drop in the sclerometric index.

Photo 4. Dynamic and sonic auscultation tests.

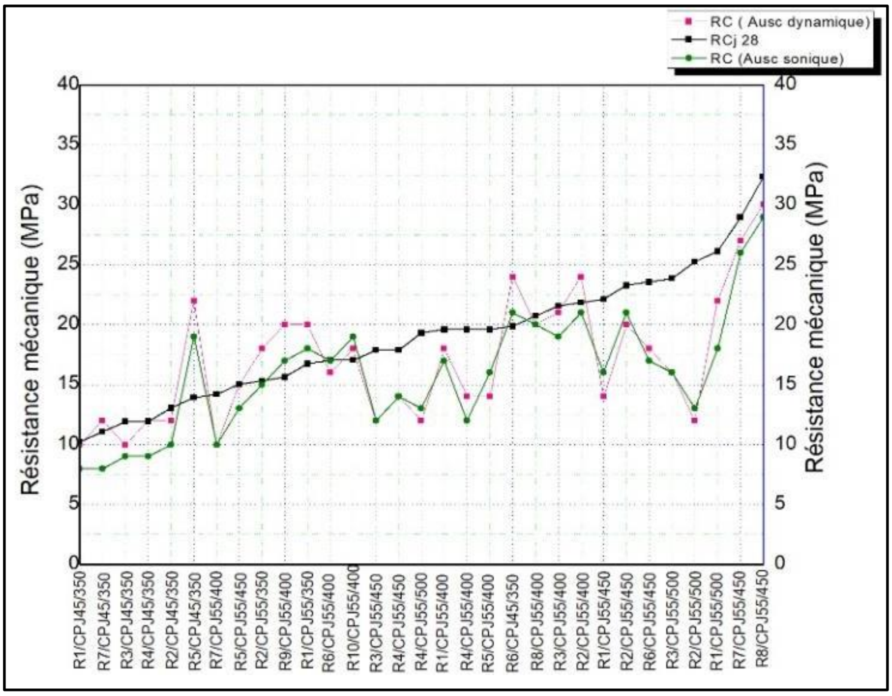


Figure 5. Relationship between destructive and non-destructive concrete measurements.

3.2.5. Ratio of mechanical strength to dry density.

Figure 6 shows that the evolution of mechanical strength depends on the cement dosage and the aggregates nature, but does not always depend on the dry density except in the case of aggregates of the same nature.

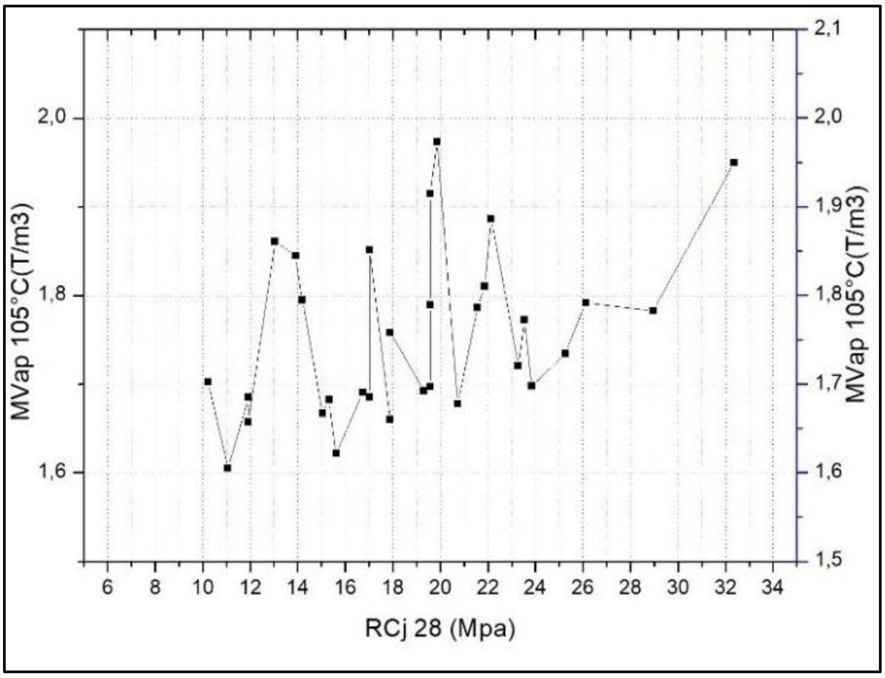


Figure 6. Ratio of mechanical strength to density of different concrete dosages.

3.3. X-ray diffraction analysis of samples.

The X-ray diffractogram presented in Figure 7, indicated that the samples 1 and 2 are essentially composed of calcite ($CaCO_3$), some traces of quartz (SiO_2) and dolomite ($CaMg(CO_3)_2$); while the sample 3 includes a high proportion of quartz (SiO_2) and sodium feldspar ($NaAlSi_3O_8$). The diffractogram of Figure 8, of concrete samples shows the presence of main lines of Alite (A), Belite

(B), Celite (C*), as well as Calcite (C) in travertine and quartz -based concrete (Q). In concrete brick waste, the respective chemical formulas are Ca_3SiO_5, Ca_2SiO_4, $Ca_3Al_2O_6$, $CaCO_3$, SiO_2.

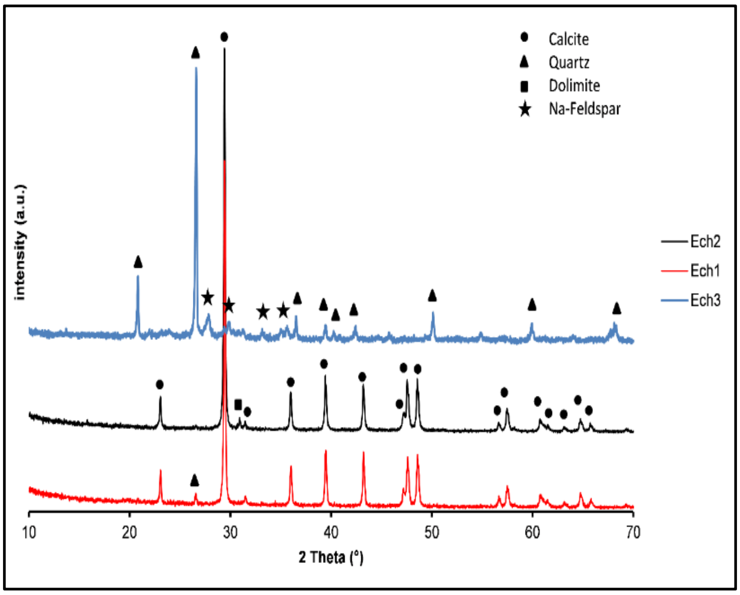


Figure 7. X-ray diffraction analysis of concrete aggregates (Ech1: travertine T1, Ech2: travertine T2, Ech3: brick waste BC)

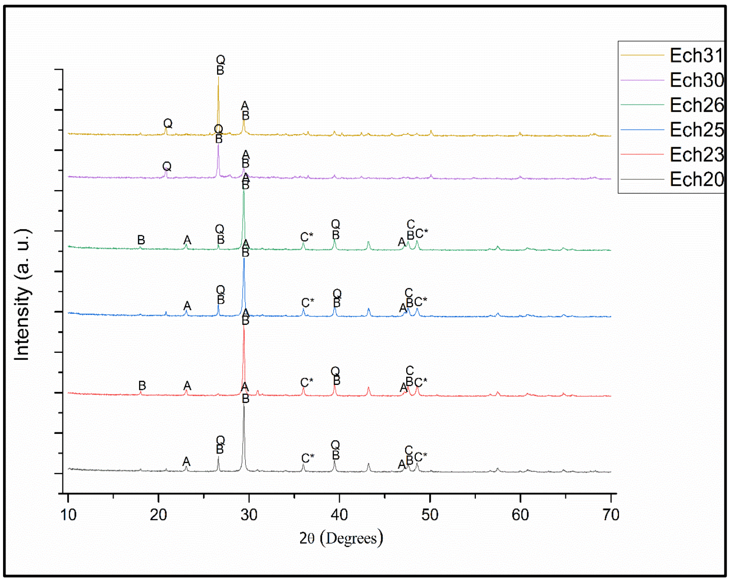


Figure 8. X-ray diffraction analysis of concrete (See Table 3.)

3.4. Thermal characterization of different types of concrete.

3.4.1. Thermal analysis by ATG and ATD

The thermal profiles obtained for the raw samples in Figures 9, 10 and 11, show the presence of a significant mass loss in the case of travertine samples (Ech 1 and 2), while the sample of terracotta bricks (Ech 3) does not record any loss of mass at high temperatures.

Thus, travertine samples show a small mass loss that begins around 230 °C accompanied by an exothermic peak recorded in ATD, this loss results from the decomposition of organic matter present in travertine. Another exothermic peak is also observed at about 450 ° C without loss of mass in thermogravimetric analysis, which corresponds to the allotropic transformation of travertine

from the aragonic form to the calcite form. This thermal profile is commonly found in the bones of marine molluscs, mainly composed of the aragonic form of limestone and a low proportion of chitin [42, 43].

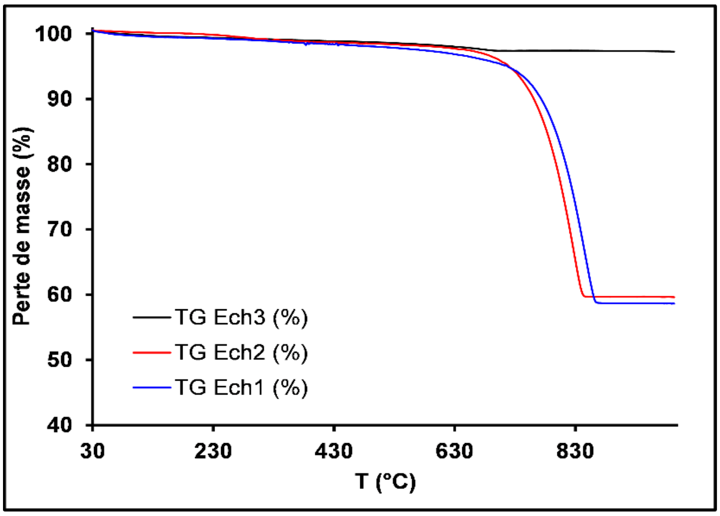


Figure 9. ATG thermal analysis of concrete aggregates (Ech1: travertine T1, Ech2: travertine T2, Ech3: brick waste BC)

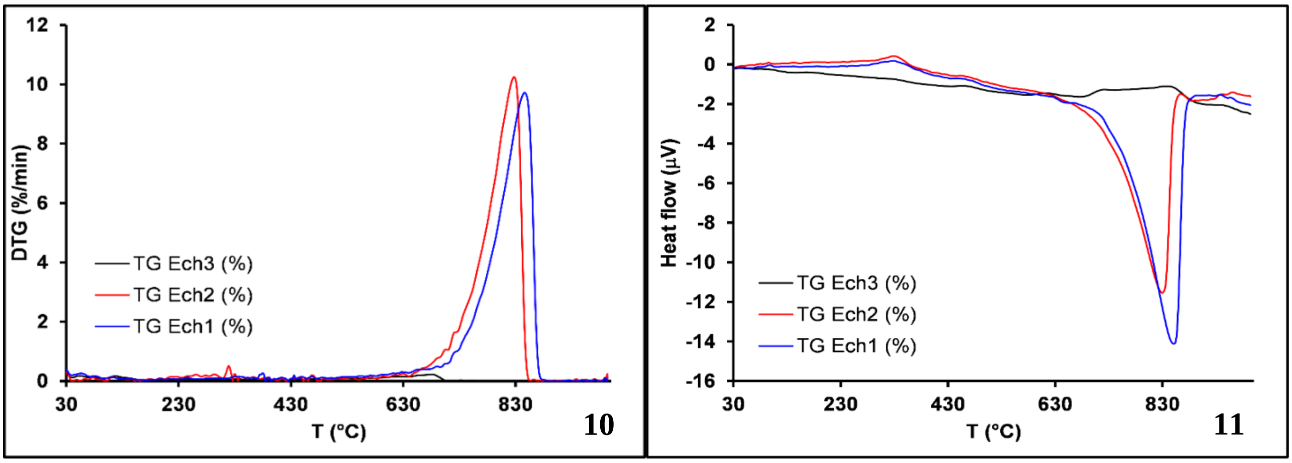


Figure 10 and 11. ATD thermal analysis of concrete aggregates (Ech1: travertine T1, Ech2: travertine T2, Ech3: brick waste BC)

The last significant mass loss is recorded from 630 °C accompanied by an intense endothermic peak that corresponds to the decomposition of travertine to give the CaO according to the equation:

$$CaCO_3 \rightarrow CaO + CO_2$$
$$100\ g/mol \rightarrow 56\ g/mol + 44\ g/mol$$

As a reference pure limestone, the amount of mass loss corresponding to carbon dioxide is 44 g/mol thus equivalent to 44 %, therefore the degree of purity of Ech1 travertine amounts to 89.77 % while it is of the order of 86.36 % for Ech2.

Following the DRX analysis and the TG and TD analysis we can deduce that:

Ech1 contains 10.23% impurities (SiO_2 + organic matter).

Ech2 contains 13.64% impurities (Dolomite + organic matter).

On the other hand, terracotta brick is a refractory material; it does not show any loss of mass in the temperature range considered (30 to 1000 °C). The very small loss observed at around 630 °C is due to the presence of a small amount of limestone and organic matter in the terracotta brick sample.

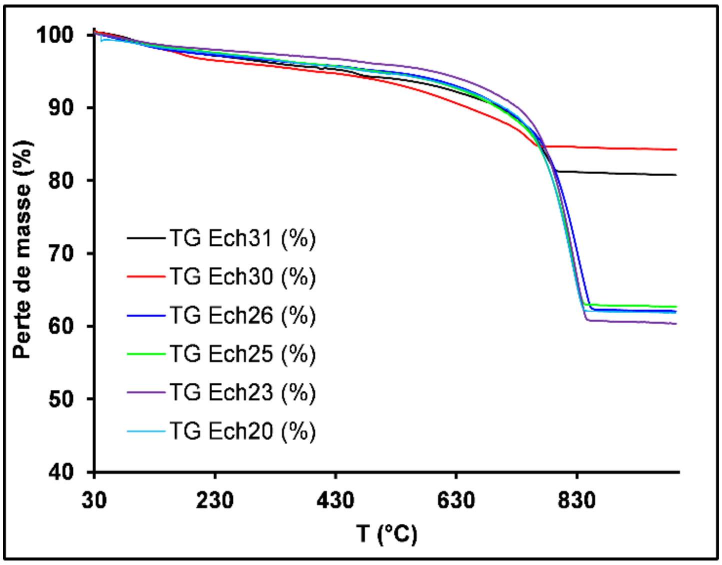


Figure 12. Thermal analysis by ATG of concretes (See Table 3)

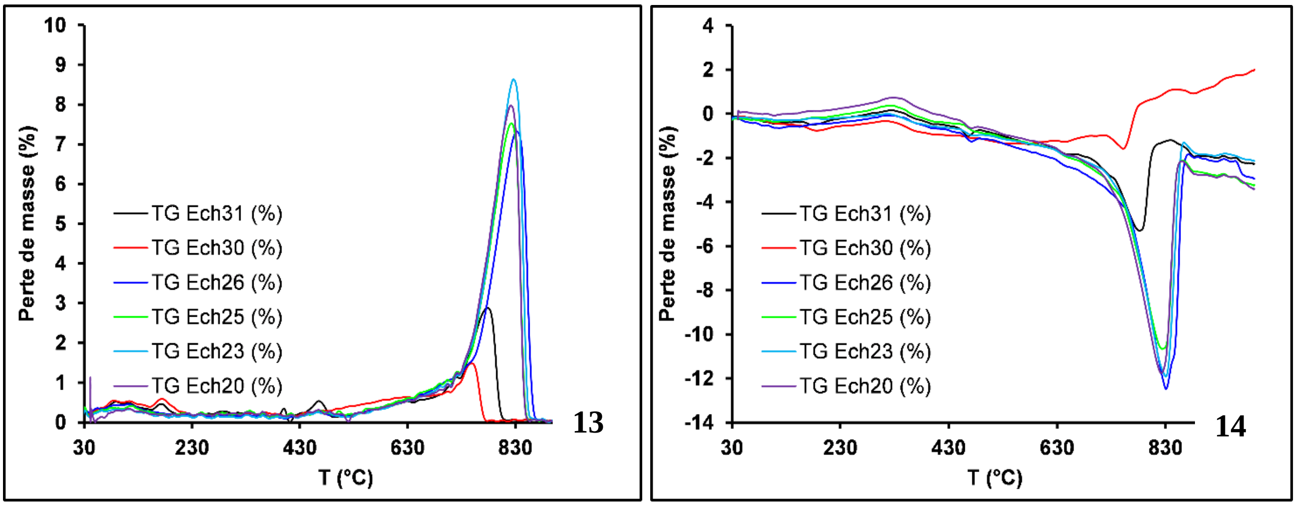


Figure 13 and 14. Thermal analysis by DTA of concretes (See Table 3)

The thermal analysis of concrete samples samples in Figures 12, 13 and 14, shows thermal profiles in relation to their composition initially taken during their preparation. In addition, the mass losses recorded all result from the decomposition of travertine in samples 20, 23, 25 and 26. The percentage of loss due to the decomposition of organic matter and degradation of $CaCO_3$ is reasonable and consistent with the average proportion of travertine, added to these samples by 64 % (the average purity of travertine used is 88% and the percentage of carbon dioxide loss for pure limestone is equivalent to 44 %, the loss is therefore of the order of 25 %). Samples 30 and 31 are refractory; the mass loss recorded is small and probably due to the presence of a small proportion of marine mollusc litter and organic matter in sea sand and in terracotta brick waste [44-46].

3.4.2. Measurement of thermal conductivity using the Hot disk device

The results in Tables 4, reveal that concrete based on brick waste is characterized by a low thermal conductivity compared to that of travertine despite the high porosity of the latter. The addition of SiO_2-rich sea sand to travertine-based concrete increases its mechanical strength, conductivity, thermal diffusivity, density and decreases effusively. This drop in insulating properties results mainly from the increase in the percentage of SiO_2, the conductivity of a material increases with the increase in ambient temperature for several minerals including quartz [47-49].

Photo 5. Samples for thermal conductivity tests.

Sample 30

Sample	T (°C)	Conductivity (W/mK)	Diffusivity (mm²/s)	Effusivity Ws¹´²/m²K
R7/CPJ55/450	**25.0**	**0.813**	**0.6469**	**1012**
R7/CPJ55/450	**25.0**	**0.821**	**0.6590**	**1012**
R7/CPJ55/450	**25.0**	**0.827**	**0.6571**	**1020**

Sample 23

Sample	T (°C)	Conductivity (W/mK)	Diffusivity (mm²/s)	Effusivity Ws¹´²/m²K
R2/CPJ55/500	**25.0**	**1.055**	**0.5284**	**1452**
R2/CPJ55/500	**25.0**	**1.051**	**0.5291**	**1444**
R2/CPJ55/500	**25.0**	**1.055**	**0.5228**	**1460**

Sample 20

Sample	T (°C)	Conductivity (W/mK)	Diffusivity (mm²/s)	Effusivity Ws¹´²/m²K
R1/CPJ55/500	**25.0**	**1.103**	**0.8162**	**1222**
R1/CPJ55/500	**25.0**	**1.112**	**0.7930**	**1249**
R1/CPJ55/500	**25.0**	**1.109**	**0.8032**	**1238**

Tables 4. Results of conductivity, diffusivity and thermal effusivity of three references of concrete based on lightened aggregate

Conclusion

This new travertine-based concrete, used as a load-bearing structure, must always be protected by a layer of mortar in order to avoid any kind of mechanical performance drop under the effect of aggressive stresses. Conducting this research has allowed us to obtain the following results:

- a lightweight concrete of class LC1.6, LC1.8 and LC2.1 according to the new version of the NF EN 206 standard;
- a compressive strength corresponding to classes LC12/13, LC16/18, LC20/22, LC25/28 and LC30/33 according to NF EN 206-1. These classes demonstrate the possibility of obtaining compressive strengths comparable to those obtained from ordinary concrete;
- a possibility of achieving resistances greater than 35Mpa with a density ranging from 1.8 to 2 T/m^3 by increasing the correction in sand and/or cement dosing, for references R8/CPJ55/450 and R7/CPJ55/450.

In addition, the research highlights:

- the addition of brick waste with travertine in the concrete, improves mechanical strength without significantly reducing density;
- travertine with a fragmentation resistance of less than at least 55 and brick waste with a fragmentation resistance of less than 25 will be suitable for concrete based on light aggregate;
- thermal conductivity (from 0.82 to 1.05 W/mK) similar to that of silico-limestone bricks, hollow cement agglomerates and cavernous concretes.
- a reduction in thermal conductivity of 0.83 to 1.18 for concrete based on brick waste and from 0.6 to 0.95 for travertine-based concrete compared to common concrete [50].

To conclude, this new concrete can therefore be used as a load-bearing structure with thermal qualities equivalent to the separation elements, knowing that it is possible to increase thermal performance by reducing the cement dosage in the event that this concrete is used as a separation material in the building.

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