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# EXPERIMENTAL CONTRIBUTION TO STUDY THE PHYSICO-MECHANICAL AND THERMAL PROPERTIES OF LIGHTWEIGHT CELLULAR CONCRETE PREPARED WITH DIFFERENT TYPES OF SAND AND WASTE MARBLE POWDER

Moufida BOUREMA[1*], Idriss GOUAL[1], Ahmida FERHAT[1]

***Abstract***

*Algeria is currently undergoing an evolution in civil engineering, which has resulted in a higher use of aggregates, especially sand. This study contributes to the development of locally produced materials. Its goal is to explore how the type of sand and waste marble powder (WMP), which can be used as a partial replacement of cement and aluminum powder (Al) with different percentages as an expansive agent, can affect physico-mechanical properties such as the bulk density and mechanical strength at 28 and 90 days, as well as the thermal conductivity of lightweight cellular concrete. Non-autoclaved cellular concretes (CC) were investigated based on three types of sand, i.e., sea sand (SS), river sand (RS), and waste marble sand (WMS); a hydraulic binder (a mix of cement and waste marble powder), and aluminum powder. The experimental results indicate that the nature and particle size distribution of the sand used had an impact on the properties of the CCs. Furthermore, it can be seen that the increased aluminum contents decrease the density, mechanical strength, and thermal characteristics of the CCs. Using 10-15% WMP as a cement substitute improves the mechanical strength, offers better thermal conductivity values, and contributes to sustainable development by developing a new class of environmentally friendly cellular concrete.*

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***Key words***

- Lightweight cellular concrete,
- Sand,
- Aluminum powder,
- Thermal conductivity,
- Physico-mechanical properties.

## 1 INTRODUCTION

In recent decades, the improvement of structures and structural building works has resulted in significant energy use. It has become critical to consider all of the potential outcomes of waste reuse and recovery in the context of manageable improvements and environmental preservation, because the need to recoup materials is taken into account on the one hand, while, on the other hand, there is a need to protect the environment. Like some other European and African countries, Algeria is experiencing a severe shortage of structural materials, particularly cement and sand (Belachia et al., 2011; Akbulut et al., 2007; Binici et al., 2008). Similarly, ongoing research has focused on the valorization of alternative materials to manufacture low-cost and durable structural materials (Cisse et al., 2000). In terms of valuing Algeria's many assets (natural and industrial) and their possible misuse, lightweight concrete is intriguing from both financial and environmental standpoints. A few scientists have shown that the removal of wellsprings of regular fine totals, such as river sand, poses a risk of debase-

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ment that is harmful to nature (Sun et al., 2016; Dias, et al., 2008). Different specialists have recently become interested in the use of marble powder as an alternative material (Agarwal et al., 2006). According to these findings, the presence of marble powder in a cementitious grid improves compressive quality at an early age (Messaoudene et al., 2011). The effect of marble powder as a filler has been studied (Topcu et al., 2009). The mechanical strength of cement decreases; however, its handling is unaffected for a large amount of marble (Corinaldesi et al., 2010). According to the results, replacing Portland cement with 10% marble powder improves the compressive strength of concrete by more than 50 MPa at 28 days (Messaoudene et al., 2011).

Cellular concrete is a cost-effective alternative for producing large-scale lightweight materials and components. It is composed of various components such as fine sand (silica sand powder), cement, hydrated lime, water, and an expansive agent (Ramamurthy et al., 2009). The method of autoclaving is frequently employed in the manufacturing process to generate autoclaved aerated concrete (AAC), by which millions of tiny non-connecting cells are created when aluminum powder is combined with calcium hydroxide in the presence of water resulting from the hydration of the cement/lime to form hydrogen gas (Jerman et al., 2013; Damene et al., 2018); it generates large-scale pores due to the extension of the mixture, with the pore space accounting for 60 to 90 % of the total volume (Narayanan et al., 2000); however, some hydrogen gas is ineffective in providing pores because of the high amount of aluminum powder. The chemical reaction that occurs as follows:

$$2\,Al + 3\,Ca(OH)_2 + 6\,H_2O \rightarrow 3\,CaO.Al_2O_3.6\,H_2O + 3H_2$$

Nevertheless, the cost of producing AAC is still highly expensive because it requires an autoclave and uses a lot of energy. The porosity of cellular concrete is affected by several parameters, including the composition of the mix design, foam agents, and curing types. The findings suggest that the porosity of aluminum powder increases up to 0.4 % before decreasing to between 0.6 - 0.8%.The mechanical strength of cellular concrete increases as its porosity decreases (Guglielmi et al., 2010). The pore size and microstructure affect properties such as the cc's strength, durability, heat transmission, and moisture transport (Narayanan et al., 2000; Torquato, et al., 2002). Various studies (Lian et al., 2011; Boutin, 1996) discovered that the CC's compressive strength is proportional to its density and that it increases as the density increases (Mugahed et al., 2015). The latter depends on many variables, such as the rate of the foaming agent, which decreases the density as it increases, because it creates air voids, the w/c proportion, the method of curing, which can be non-autoclaved or autoclaved (Narayanan et al., 2000), and the type of sand. The particles damage the strength of the cellular concrete because its expansion affects the pore size in the paste (Nambiar et al., 2006). Indeed, some researchers (Cabrillac et al., 2006; Damene et al., 2018) studied lightweight cellular concrete and concluded that the use of hydrated lime as a partial substitute for cement and aluminum content tended to increase the total porosity of the matrix and decrease both the thermal conductivity and compressive strength. (Ramamurthy et al., 2009), and (Richard et al., 2013) reported that foamed concrete has various features such as a low density, which improves its thermal performance due to its microstructure.

With the aim of developing local materials, our research sought to investigate the impact of different types of sand on the physico-mechanical and thermal properties of cellular concrete without requiring any autoclave treatment by a lightening process in a Sand/Binder mineral paste by a chemical reaction with aluminum powder that confers a cellular structure on the material. A secondary purpose was to determine the effects of waste marble powder content as a partial replacement for different aluminum dosages on physico-mechanical behavior such as the bulk density and mechanical strengths at 28 and 90 days, as well as the thermal conductivity of cellular concrete.

## 2 EXPERIMENTAL DETAILS

### 2.1 Materials

The samples for the binder are a mixture of cement and waste marble powder, which was substituted in the cement mass (0%, 10%, 15%, and 20%). The cement used was a CEM I 42.5 ordinary Portland type, manufactured by the LE KARROUBA factory located in Tunisia, according to the European Standards EN-197/1. Table 1 lists its chemical composition and its physical and mechanical properties. Fines must be added to the concrete to increase its compactness by completing the granular framework, thereby minimizing the amount of expensive cement in the binder. The waste marble powder (WMP) is a fine that comes from a marble quarry in the Skikda region (Algeria); it was prepared by sifting it (in a sieve opening of 80 μm) and crushing the waste marble sand used. Its characteristics are given in Table 2. Three types of sand were used for making the cellular concrete, i.e., sea sand (SS), obtained from the region of Jean dark located in Skikda; river sand (RS), obtained from the region of Ibn ziad located in northwestern Constantine; and waste marble sand (WMS), from the marble quarry of Fil-fila, situated 25 km to the east of the region of Skikda.The sands have maximum grain diameters of 1 mm, 4 mm and 3 mm, respectively. As established according to standard NF P18-560, these sands have a continuous particle size distribution. RS has the highest fineness modulus, i.e., (3.06), indicating that it is the coarsest sand, whereas SS and WMS have fineness moduli of 2.10 and 2.03 respectively, and are finer sands. The "SS and RS sand equivalent" values are measured according to the NF P 18-598 standard, which shows that SS and RS are clean sands, while the "WMS sand equivalent" is 65%. This value remains the value recommended for concrete and mortar (Belhadj et al., 2014). Table 3 and Fig. 1 show the physical properties and the grading curves of these various sands. Aluminum powder (Al) with a fineness of 100 μm commercialised by SIALCHIM Company and a purity of 99% and a molar mass of 26.98 $g.mol^{-1}$ was used as the expanding agent in the lightening process. The water (W) used for mixing the CC constituents was untreated tap water. The PH was close to 7.34 to T ° = 13.2°C when tested on a regular basis.

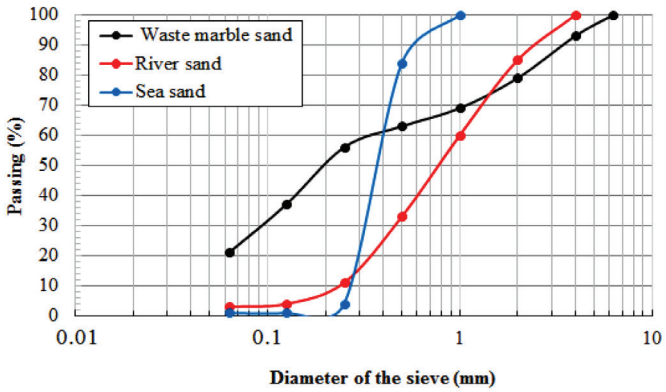



**Fig. 1** *Grading curve of the sands*

## 2.2 Mix proportions

All of the mixtures were made using an S/B ratio of 3/2. There were 60 compositions produced in total, which were proportioned and divided into three groups using the three distinct sands, i.e., SS, RS, and WMS, each with twenty mixes. Only cement was used as a binder in the composition of the control mix with (WMP /B) =0% and (Al/B) =0%. Whilst the cement was partially substituted with WMP at ratios of (10%, 15%, and 20%), varying percentages of the expanding agent (Al) by the weight of the binder (from 0 to 1 %, with 0.25% increments) were included for each mixture.

The amount of the W/B ratio was defined for each mix design of the different sands by studying the flow time results of the fresh concrete obtained using an LCPC maniabilimeter in order to satisfy the workability requirement and the RILEM standards for lightweight concrete (RILEM, 1993).The W/ B ratio of about 50% for SS, 55% for RS, and 60% for WMS (see table 4) shows the proportions of all the CC mixtures.

**Tab. 1** *Properties of the cement*

| Properties | Value |
|---|---|
| Initial setting time (min) | 210 |
| Final setting time (min) | 264 |
| Specific gravity (g/cm$^3$) | 3.2 |
| Blaine fineness (cm$^2$/g) | 38.69 |
| Compressive strength at 2 days (MPa) | 21.9 |
| Compressive strength at 14 days (MPa) | 37.6 |
| Compressive strength at 28 days (MPa) | 50.10 |
| Flexural strength at 2 days (MPa) | 4.68 |
| Flexural strength at 7 days (MPa) | 7.01 |
| Flexural strength at 28 days (MPa) | 8.37 |
| $C_4AF$ (%) | 14 |
| $C_3A$ (%) | 3.14 |
| $C_3S$ (%) | 67.54 |
| $C_2S$ (%) | 8.83 |

**Tab. 2** *Properties of WMP*

| Properties | WMP |
|---|---|
| **Color** | **White** |
| Specific gravity (g/cm3) | 2.8 |
| Blaine fineness (cm2/g) | 58.04 |
| CaO | 59.54 |
| $Al_2O_3$ | 1.06 |
| $Fe_2O_3$ | 0.13 |
| $SiO_2$ | 1.76 |
| Mg O | 1.03 |
| $Na_2O$ | 0.04 |
| $K_2O$ | 0.03 |
| $SO_3$ | 0.01 |
| $Cl^-$ | - |

**Tab. 3** *Physical properties of the sands used*

| Properties | Sand type | | | |
|---|---|---|---|---|
| | Unit | SS | RS | WMS |
| Absolute density | (kg/m$^3$) | 2580 | 2610 | 2600 |
| Sand equivalent | (%) | 95 | 77 | 65 |
| Fineness modulus | (%) | 2.1 | 3.06 | 2.03 |
| Fines content | (%) | 1 | 3 | 21 |

**Tab. 4** *Mix proportions of the CC mixtures*

| CC mixture | B=WMP+ C | | % S/B | % Al /B | % W/B |
|---|---|---|---|---|---|
| | % WMP/B | % C /B | | | |
| **Group 1** | | | | | |
| SSCC | 0 | 100 | 150 | 0 | 0.50 |
| SSCC WMP 10% | 10 | 90 | | 0.25 | |
| SSCC WMP 15% | 15 | 85 | | 0.50 | |
| SSCC WMP 20% | 20 | 80 | | 0.75 | |
| | | | | 1 | |
| **Group 2** | | | | | |
| RSCC | 0 | 100 | 150 | 0 | 0.55 |
| RSCC WMP 10% | 10 | 90 | | 0.25 | |
| RSCC WMP 15% | 15 | 85 | | 0.50 | |
| RSCC WMP 20% | 20 | 80 | | 0.75 | |
| | | | | 1 | |
| **Group 3** | | | | | |
| WMSCC | 0 | 100 | 150 | 0 | 0.60 |
| WMSCC WMP 10% | 10 | 90 | | 0.25 | |
| WMSCC WMP 15% | 15 | 85 | | 0.50 | |
| WMSCC WMP 20% | 20 | 80 | | 0.75 | |
| | | | | 1 | |



**Fig. 2** *volumetric expansion in the samples and distribution of the voids in the mortar matrix*

### 2.3 Mixing and moulding procedures

Regarding the cellular concretes studied, the solid elements, i.e., the "waste marble powder + cement" binder and sand, were first combined for two minutes (EN 196-1). An amount of water was added; then, the concrete was mixed for another two minutes at a low speed, followed by a pause in order to homogenize the mixture by scraping the bowl's bottom and sides. Another two minutes of mixing at a high speed followed. The expansive agent was introduced at a low speed for one minute, which was then followed by one minute at a high speed (Goual et al., 1999). All the mixtures were poured into (40 x 40 x 160 $mm^3$) prismatic moulds and stored without a cover in a storage chamber (T = 20 ± 2 ° C and RH = 95 ± 3%) . After 24h, the expanded part of the specimens was sawed before demoulding and stored in a climatic room (T = 20 ± 2 ° C and RH = 95 ± 3%) until testing. Fig.2 indicates the volumetric expansion in the samples and distribution of the voids in the mortar matrix.

### 2.4 Testing procedures

The physico-mechanical and thermal performances of the cellular concrete were determined by the dry bulk density $\rho_{app}$



**Fig. 3** *Simple compression instrument*

according to the ASTM-C134 standard by dividing the dry weight by the apparent volume of the test specimens using the following relation :

$$\rho app = \frac{\text{Dw}}{\text{L x W x H}} \quad (1)$$

where Dw, L, W, and H, are the dry weight, length, width and height of the samples respectively.

The compressive strength tests were measured according to NF EN 196-1 by carrying out on the specimens with dimensions of 40 × 40 mm test sections on short and long terms of "28 and 90 days" (Fig. 3) with a maximum compression force of 2400 N/s ± 200 N/s. The compressive strength results on each curing day corresponded to the average of the three measurements taken on the samples of each combination of the different types of sand used to make the cellular concrete.

Thermal conductivity λ and diffusivity are two standards used to measure the insulating qualities of building materials. These are determined by the components' inherent qualities, the material's microstructure, and the storage circumstances (the role of water) (RILEM, 1970). The thermal diffusivity (α), of a material is defined as the speed at which heat propagates by conduction in a medium. A material with a lower thermal diffusivity value will have a slower heat transfer rate throughout its thickness, resulting in higher insulation properties. It is calculated by dividing the thermal conductivity by the specific heat and density ($m^2/s$), as demonstrated in equation (2).

$$\alpha = \frac{\lambda}{\rho \text{Cp}} \quad (2)$$

Our interest in this study is the determination of the thermal conductivity measurements of the materials developed using the Hot Disk TPS 1500 method, which is a Hot Disk sensor in the shape of a double spiral consisting of an electrically conducting pattern. This spiral is sandwiched between two thin insulating sheets (Fig. 4(a)). When making a measurement, the Hot Disk sensor is placed between the two plane samples to be studied in dimensions of (40 x 40 x 20 $mm^3$). A chucking device was used to provide proper contact between the various components and to prevent the two samples from moving according to the experimental assembly shown in Fig. 4(b). The sample should be larger than the sensor diameter so as to avoid impact from the sample's outside boundaries and to offer reliable values for the thermal conductivity and diffusivity. The power heat flux was kept constant at 0.55 W, and

the overall duration of the transitory regime varied from 40 to 80 seconds in order to acquire accurate results.

When measuring the thermal conductivity of the sample surrounding the TPS-element, the TPS method uses a conducting pattern with a heat capacity concurrently as a heating element and a temperature sensor (Gustafsson, 1991; Bouguerra et al., 1997). The equation can be represented as the following time-dependent resistance of the TPS-element during the transient recording:

$$R(t) = R_0 (1+ \alpha \Delta T(\tau)) \quad (3)$$

where R(t) is the resistance of the TPS element at time (t) ; $R_0$ is the resistance of the TPS element at time zero; α is the temperature coefficient of the resistivity (TCR); and $\Delta T(\tau)$ is the mean value of the increase in the TPS-element's temperature. The graph of the experimental temperatures $T_0$ recorded at each second is then obtained. The thermograph recording the increase in temperature in the TPS probe revealed that a range of measuring points between 60 and 160 of each series of measurements could be used to evaluate the thermal parameters.



*Fig. 4 (a) Hot Disk sensor*

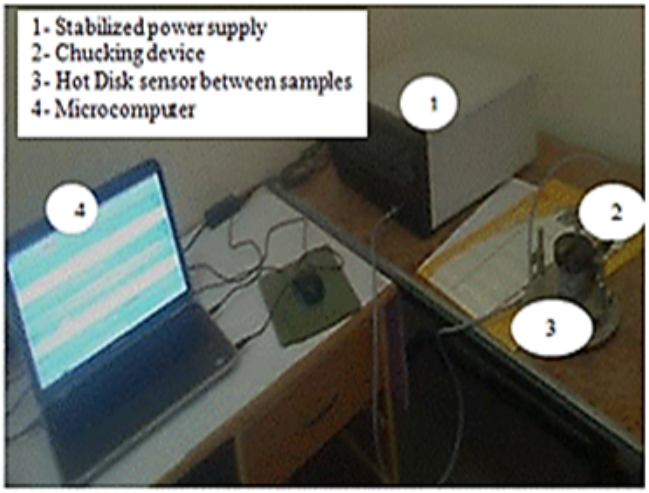



*Fig. 4 (b) Experimental assembly used in the Hot Disk technique*

**Fig. 4** *Experimental assembly used in the Hot Disk technique*

## 3 RESULTS AND DISCUSSION

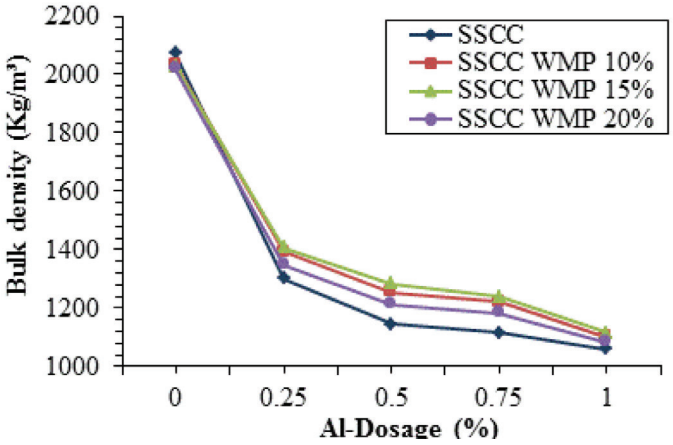
### 3.1 Bulk density

The density of cellular concrete is one of its most important features. Based on this property, it is possible to classify the type of concrete and identify its field of application. The experimental results of the dry bulk density of the CCs developed as a function of the different percentages of the aluminum powder ranging from 0 to 1 % for the different WMP contents are presented in (Fig. 5). The curves show that the bulk density of cellular concrete made with the various types of sand decrease significantly as the aluminum content increases due to the decreasing solid content and that the voids created by the hydrogen released by the response of the aluminum lighten the material (Nambiar and Ramamurthy, 2006 a,b) and lead to high variations in the density (Ramamurthy et al., 2009). Furthermore, for the various aluminum powder percentages, the decrease in bulk density is more important for the reference mixtures without WMP (SSCC, RSCC, and WMSCC). In terms of the impact of the WMP content, the results indicate that the bulk density increases at the level [0–10%] of the WMP content for the compositions of the WMSCC developed and at the level [0–15%] of the WMP content for the compositions of the SSCC and RSCC developed, which also had the maximum compressive strength of the $CC_S$. The addition of WMP had a filling effect, which made the matrix more compact and dense (Vardhan et al., 2019). The decreasing rates of the bulk density vary from 48.7 % for the SSCC composition without WMP to 44.9 % for the composition containing 15% of WMP (SSCC WMP 15%) when the aluminum rate percentage is between 0 to 1 % (Fig. 5(a)). The rate of decay in the dry bulk density decreased from 47.8 % for the RSCC to 43.6 % for the RSCC WMP 15% compositions as the aluminum content varied from 0% to 1% (Fig. 5(b)). This parameter varied for the WMSCC from 48.2 % to 45.15 % for the WMSCC WMP 10% compositions for the same range of the aluminum dosage (Fig. 5(c)). It can be seen that the densities reached a specific threshold (0.5% of the aluminum content in this case study), varied slightly, and then became constant for the remaining percentages of aluminum. These findings confirm those of (Cabrillac et al., 2006; Damene et al., 2014).

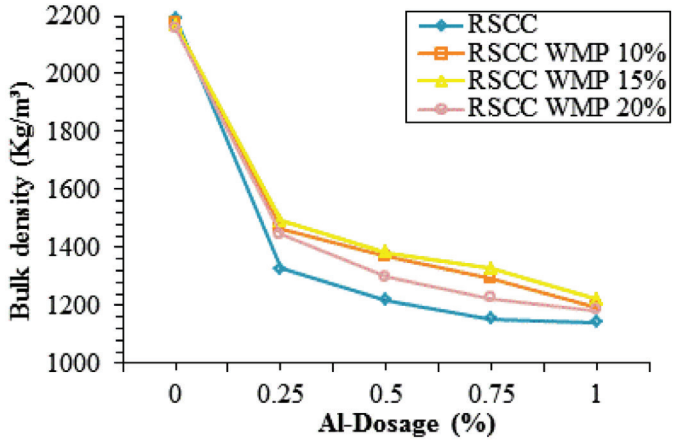
Regarding the effect of the type of sand used, the findings also revealed that the changing of the type of sand is essential for reaching the desired density in cellular concrete. The results show that the river sand resulted in the highest density, followed by the waste marble sand, while the sea sand resulted in the lowest density when the aluminum content varied from 0 to 1 %. This is mainly due to the three sands' distinct grain size distributions and their different physical properties (shape, density, etc.).

### 3.2 Compressive strength

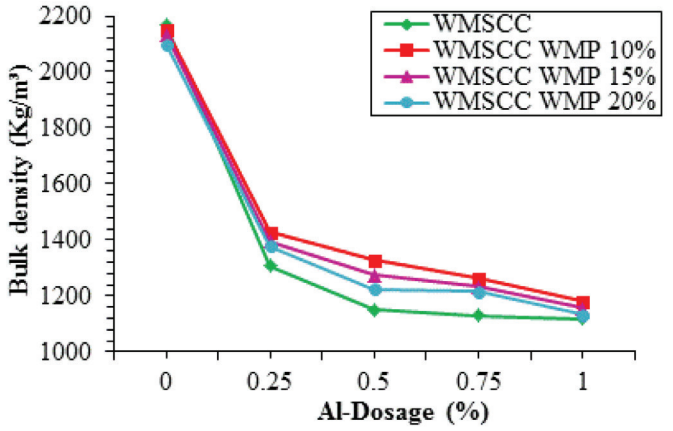
Several factors affect compressive strength, which is directly correlated with density (Lian et al., 2011). Fig.6 illustrate the variations of compressive strength as a function of the dosage of aluminum for different substitution ratios of the waste marble powder content (WMP/B) at the various cur-




*5(a) Sea sand cellular concrete (SSCCs)*




*5(b) River sand cellular concrete (RSCCs)*

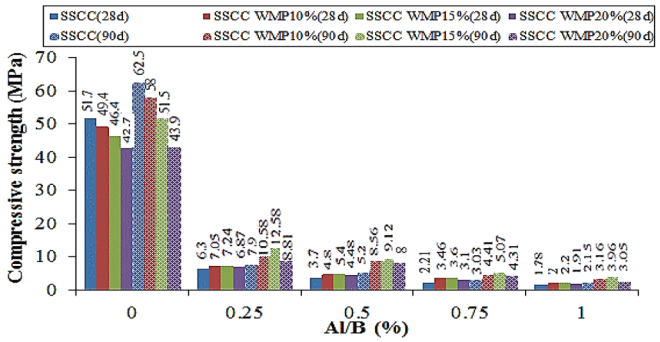



*5(c) Waste marble sand cellular concrete (WMSCCs)*

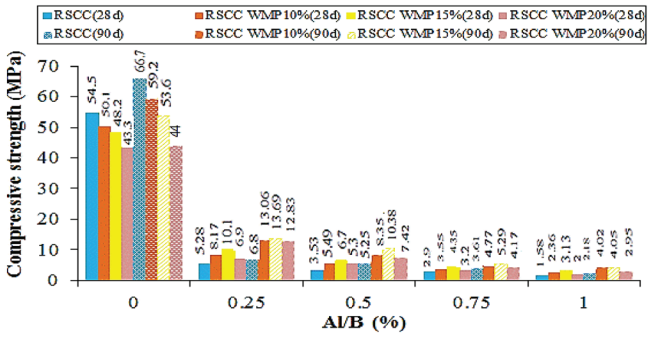
***Fig. 5** Evolution of CC's bulk density as a function of the aluminum content for different percentages of WMP*

ing ages of 28 and 90 days. Each compressive strength value given in this paper is the average of all three specimens. These findings reveal that the compressive strength decreased noticeably in the mixtures as a function of the aluminium content ranging from 0 to 1%. This is mainly due to the appearance of porosity of the materials developed, since higher amounts of the foaming agent used generally create voids in the matrix and result in a lower density (Nambiar and Ramamurthy, 2006 a,b). The decrease in compressive strength is more significant for the control samples (reference mixtures) for the zero WMP content. Concerning the effect of the WMP content on the compressive strength, the highest compressive strength was obtained for the SSCC WMP15%, the RSCCWMP 15% (85%C+15%WMP) and for the WMSCCWMP 10%(90%C+10% WMP); the compressive strength results of these compositions was about 5.4MPa, 6.7 MPa, and 4.6 MPa respectively at 28 days and reached 9.12 MPa, 10.38 MPa, and 8.74 MPa at 90 days for the 0.5% aluminum content. According to (Shirule et al., 2012), the pore-filling effect of the fine marble dust enhances the cement matrix and transition zone (TZ) surrounding the aggregate qualities, thereby increasing the cement's compressive strength as the replacement ratio of marble dust rises to 15.0%. Additionally, the waste marble enhances the binding capacity of the concrete matrix at the chemical level. Even though marble is not a pozzolanic material, the reaction between the calcite in the marble powder with the $C_3A$ of cement to create calcium carbo-aluminate results in a compact structure and improves the compressive strength of the mix containing marble powder (Munir et al., 2017; Vardhan et al., 2019). The compressive strength results of the CCs developed for all the WMP contents can be classified as a lightweight concrete for construction and insulation according to the standards required by (RILEM, 1978) other than the compositions above a 0.5% aluminum content, the compressive strength values of which are negligible and are not in accordance with the standards in terms of the classification for lightweight concrete (Ferhat et al., 2023). In contrast, the reduction in compressive strength results was observed at a level of 20% WMP for the SSCC and RSCC, respectively and in a range [15%–20%] of WMP for WMSCC. It is easy to conclude that the microstructure of WMP can affect the strength of the samples and that a higher WMP content is unfavourable for the development of compressive strength due to the decrease in the chemical compounds ($C_3S$ and $C_2S$) in the cementitious material, which impacts the strength of the concrete (Khodabakhshian et al., 2018) and the inability of the substance to take part in the hydration process.

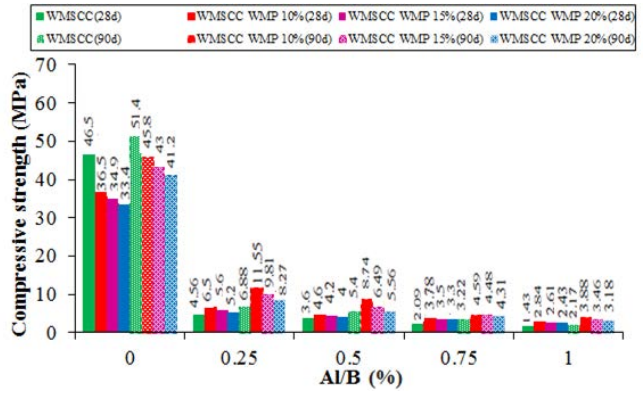
On the other hand, the types of sand differ in their mineralogical nature, grain shape, angularity, proportion of fine elements (Belhadj et al., 2014; Makhloufi et al., 2014), porosity (Tebbal & Rahmouni, 2016), and particle size (Nambiar and Ramamurthy, 2006 a,b), which negatively affect the increase and decrease in the mechanical properties of the cured cellular concrete because its addition affects the pore size in the paste. The results obtained show that the river sand results in the highest compressive strength, followed by the sea sand and waste marble sand, when the percentage of aluminum varies from 0 to 1%. It is then evident that natural sands with a well-graded particle size distribution and rounded particles exhibit the highest strength compared to waste marble sand with angular particles and a higher proportion of fines. Similar behaviors have been observed, depending on the lifespan (90 days) and compressive strength increases in all the cellular concrete compositions. Figure 7 shows the relationship between the bulk density and compressive strength at 28 days of cellular concretes. A strong relationship was observed between




*6 (a) Sea sand cellular concrete (SSCCs)*

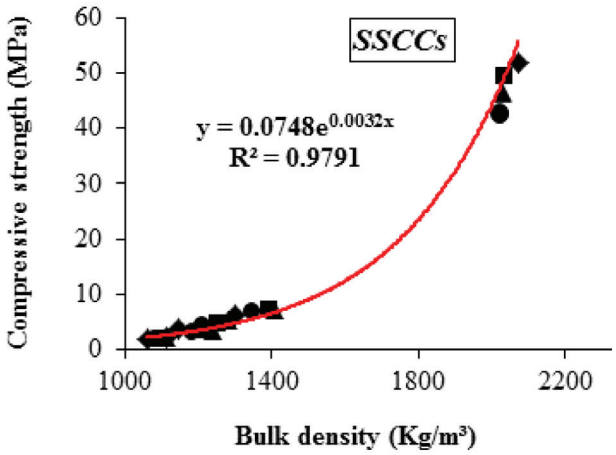



*6 (b) River sand cellular concrete (RSCCs)*

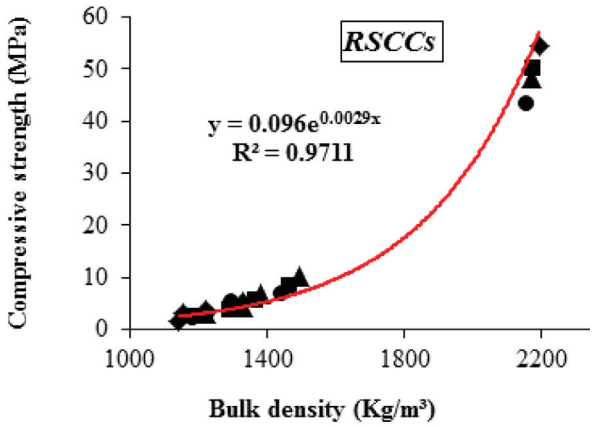



*6 (c) Waste marble sand cellular concrete (WMSCCs)*

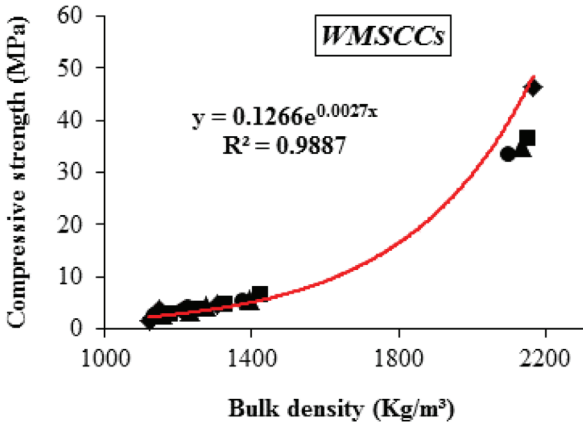
**Fig. 6** *Evolution of CC's compressive strength as a function of the aluminum content for different percentages of WMP*




*7(a) Sea sand cellular concrete (SSCCs)*




*7(b) River sand cellular concrete (RSCCs)*



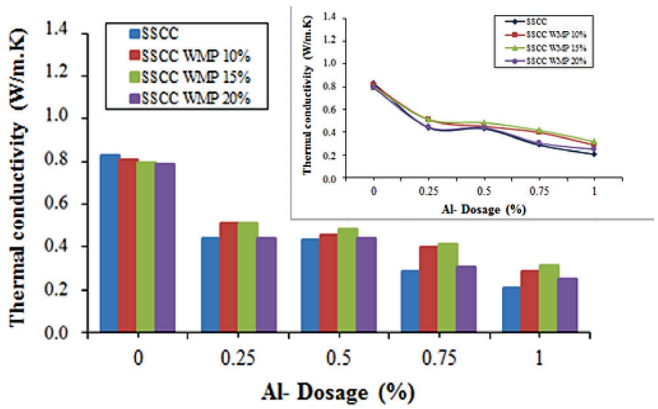

*7(c) Waste marble sand cellular concrete (WMSCCs)*

**Fig. 7** *Bulk density vs. compressive strength relationship of CC's*

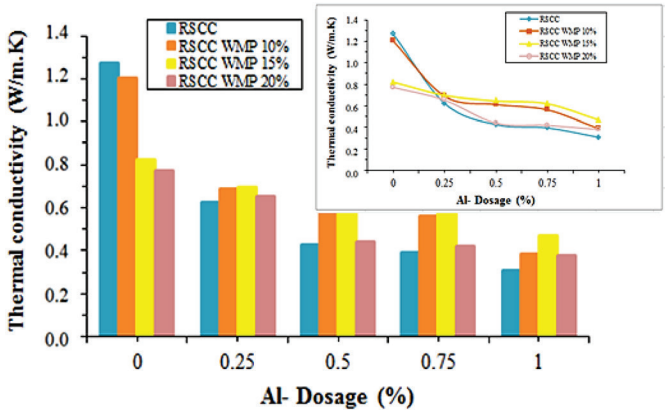
the bulk density and compressive strength, with a coefficient of correlation of 0.979, 0.971, and 0.988 for SSCCs, RSCCs, and WMSCCs, respectively.

### 3.3 Thermal conductivity

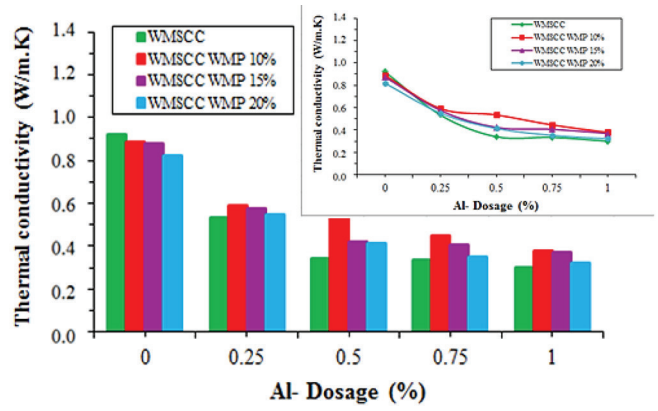
Figure 8 describes the evolution of the thermal conductivity of the cellular concrete developed as a function of the aluminum content ranging from 0 to 1% for the various WMP percentages. The results show that the thermal conductivity decreases as a function of the aluminum content (Damene et al., 2014). However, the thermal conductivity decreases significantly in compositions free of WMP (the reference mixture) compared to those containing WMP. It can be seen that the proportion of higher porosity in the matrix and the distribution of voids in the material is a key factor in the material's lightness and reduced thermal conductivity (Lian et al., 2011). Regarding the effect of the WMP content, the variations of these parameter values is very similar to the density, i.e., a lower density equals better conductivity. The ratio of the decrease was about 75% for the SSCC without WMP to 60% for the SSCC WMP 15% (Fig. 8(a)), and reached 76 % for the RSCC to 43 % for the RSCC WMP 15% (Fig. 8(b)), and on the order of 67.5 % for the WMSCC to 57 % for the WMSCC WMP 10% (Fig. 8(c)) when the aluminum dosage varied from 0 to 1%. The results of the thermal conductivity values obtained for all the compositions created from the various types of sand are in accordance with the recommendations (RILEM, 1970) for lightweight concrete for construction and insulation,




*8 (a) Sea sand cellular concrete (SSCCs)*

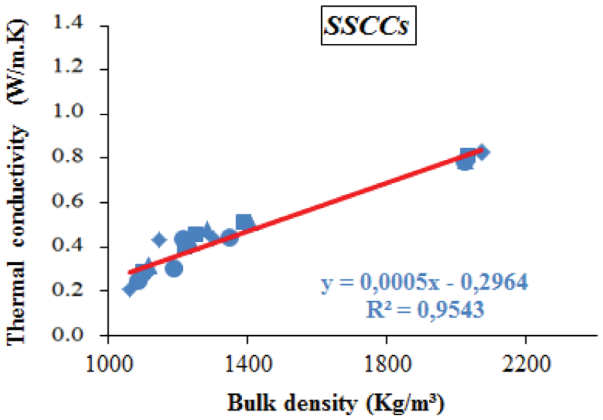



*8(b) River sand cellular concrete (RSCCs)*

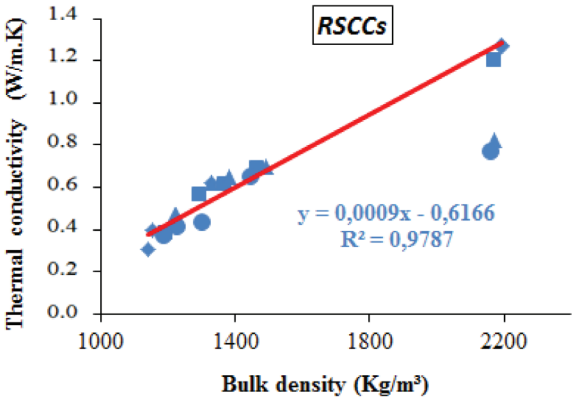



*8(c) Waste marble sand cellular concrete (WMSCCs)*

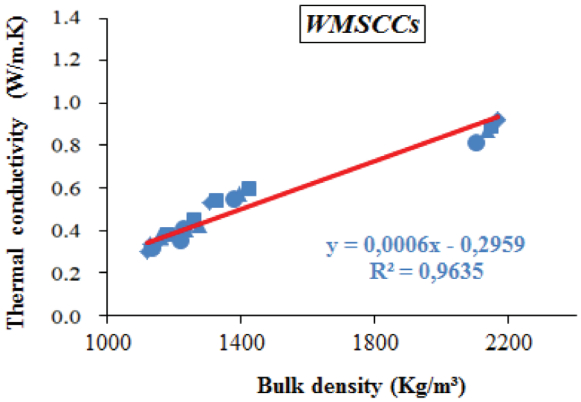
**Fig. 8** *Evolution of CCs' thermal conductivity as a function of the aluminum content for different percentages of WMP*




*9 (a) Sea sand cellular concrete (SSCCs)*




*9 (b) River sand cellular concrete (RSCCs)*




*9 (c) Waste marble sand cellular concrete (WMSCCs)*

**Fig. 9** *Thermal conductivity vs. bulk density relationship of CC's*

which specify thermal conductivity coefficients of less than 0.75 W/(m.k). The sea sand and waste marble sand yield the lowest thermal conductivity, followed by the river sand, suggesting that smaller sand particle sizes have reduced thermal conductivity and proving that finer sands are better at improving the thermal insulation properties compared to coarser sand particles that produce a higher values of thermal conductivity.

Since the thermal conductivity of cellular concrete is significantly influenced by its bulk density. Figure 9 illustrates the strong relationship between these two variables with a coefficient of correlation of 0.954, 0.978, and 0.963 for SSCCs, RSCCs, and WMSCCs, respectively.

## 4 CONCLUSIONS

This research investigated the effect of the type of sand, marble waste powder, and aluminum dosage on the physico-mechanical and thermal properties of cellular concrete. The main findings are as follows:

- In the case of cellular concrete, with the addition of WMP, the bulk density results increase to a level [0–15%] of WMP content from the mixture containing sea and river

sand (SS and RS) and to a level [0–10%] of WMP for the mixture formed with waste marble sand (WMS). Concerning the effect of the aluminum content, the density decreases with increasing the dosage of aluminum.

- The concrete's compressive strength decreases significantly as a function of the aluminum content. The experimental findings show that the compressive strength increases up to a WMP content of 15% before starting to decline at a WMP content of 20% for CCs made with RS and SS. Additionally, the compressive strength of CC compositions containing WMS decreases by the incorporation of WMP content higher than 10%. In general, 10%–15% WMP is the perfect replacement level for cement in terms of the mechanical properties of cellular concrete under the given curing conditions.
- The thermal conductivity of the CCs developed is related to their density and decreases as the aluminum dosage increases as a result of the porosity in the matrix.
- Strong correlations between bulk density vs. compressive strength, and thermal conductivity vs. bulk density of CCs were established.
- By combining the physico-mechanical and thermal characteristics as shown in this study, it can be concluded that it is possible to produce quality cellular concrete with 10-15% WMP as a partial replacement for cement. The selection of the type of sand is important in achieving the desired properties of cellular concrete in accordance with the standards required by RILEM for the classification of lightweight concrete, even though the river and sea sand offer better qualities, waste marble sand has the potential to be an alternative in the production of cellular concrete.

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## REFERENCES

**Agarwal, S. K.** – **Gulati, D. ( 2006***) Utilization of industrial wastes and unprocessed micro-fillers for making cost effective mortars,* Construction and Building Materials, vol. 20, no. 10, pp. 999–1004. DOI:10.1016/j.conbuildmat.2005.06.009.

**Akbulut, H.** – Gurer**, C. (2007)** *Use of aggregates product from marble quarry waste in asphalt pavement,* Build. Environ. vol. 42, no 5, pp. 1921-1930. DOI:10.1016/j.buildenv.2006.03.012.

**Belachia, M.** – **Hebhoub, H. (2011)** *Use of the Marble Wastes in the Hydraulic Concrete,* 6th International Advanced Technologies Symposium (IATS'11), Elazığ, Turkey, 16-18 May. DOI:10.13140/2.1.4475.2960.

**Belhadj, B. – Bederina, M. – Benguettache, Kh. – Queneudec, M. (2014)** *Effect of the type of sand on the fracture and mechanical properties of sand concrete*. Adv. Concr. Constr., 2, pp.13-27, DOI: 10.12989/acc2014.2.1.013.

**Binici, H.** – **Shah, T.** – **Aksogan, O.** – **Kaplan, H. (2008)** *Durability of concrete made with granite and marble as recycle aggregates,* J. Mater.Procs.Technol., vol. 208, no 1-3, pp. 299-308. DOI:10.1016/j.jmatprotec.2007.12.120.

**Bouguerra, A. – Laurent, J. P. – Goual, M. S. – Queneudec, M. (1997)** *The measurement of the thermal conductivity of solid aggregates using the transient plane source technique*. Journal of Physics D: Applied Physics, vol. 30, no 20, pp. 2900. DOI: 10.1088/0022-3727/30/20/018.

**Boutin, C. (1996)** *Conductivité thermique du béton cellulaire autoclave modélisation par méthode auto cohérente.* Matériaux et constructions, vol. 29, no 10, pp. 609-615. Available at: https://hal.archives-ouvertes.fr/hal-00941106.

**Cabrillac, R. – Fiorio, B. – Liss Beaucour, A. – Dumontet, H. – Ortola, S. (2006)** *Experimental study of the mechanical anisotropy of aerated concretes and of the adjustment parameters of the introduced porosity*.Constr. Build. Mater., vol. 20, no 5, pp. 286-295. DOI:10.1016/j.conbuildmat.2005.01.023.

**Cisse,I. K.** – **Laquerbe, M. ( 2000 )** *Mechanical characterization of filler sandcretes with rice husk ash additions : Study applied of Senegal.* Cement and Concrete Research, vol. 30, no 1, pp. 13-18.

DOI: 10.1016/S0008-8846(99)00182-9.

**Corinaldesi, V.** – **Giacomo, M.** – **Naik, TR. (2010)** *Characterization of marble powder for its use in mortar and concrete* .Construction and Building Materials, vol. 24, no 1, pp. 113-117.

DOI: 10.1016/j.conbuildmat.2009.08.013.

**Damene, Z. – Goual, M. S. – Saiti, I. – Benhassine, N. – Ferhat, A. ( 2014)** *Study of the effect of aluminum content and c / s ratio on the physico-mechanical and thermal properties of a lightweight concrete made from sand dune*. J Fundment Appl Sci, vol. 6, no 2, pp. 220-228. DOI: 10.4314/jfas.v6i2.8.

**Damene, Z.** – **Goual, M. S. – Houessou, J. – Dheilly, R. M. – Goullieux, A. – Quéneudec, M. (2018)** *The use of southern Algeria dune sand in cellular lightweight concrete manufacturing: effect of lime and aluminium content on porosity, compressive strength and thermal conductivity of elaborated materials*. European Journal of Environmental and Civil Engineering, vol. 22, no 10, pp. 1273-1289. DOI: 10.1080/19648189.2016.1256233.

**Dias, W. P. S. – Seneviratne, G. A. P. S. N. – Nanayakkara, S.M.A. (2008)** *Offshore sand for reinforced concrete.* Construction and Building Materials, 22(7), pp.1377-1384. DOI: 10.1016/j.conbuildmat.2007.04.006.

**Ferhat, A. – Goual, M.S. – Damene, Z. – Quéneudec-t'Kint, M. (2023).** *Experimental study on the effect of lime and aluminium content on porosity, introduced porosity, compressive strength and thermal conductivity of a lightweight cellular concrete based on limestone sand*. Construction and Building Materials, vol. 392, pp. 131552. DOI: 10.1016/j.conbuildmat.2023.131552.

**Goual, M. S. – Bali, A. – Queneudec, M. (1999)** *Effective thermal conductivity of clayey aerated concrete in the dry state: experimental results and modelling.* Journal of Physics D: Applied Physics, vol. 32, no 23, pp. 3041. DOI: 10.1088/0022-3727/32/23/310.

**Guglielmi, P.O.** – **Silva, W. R. L.** – **Repette, W. L. – Hotza, D. (2010)** *Porosity and Mechanical Strength of an Autoclaved Clayey Cellular Concrete.* Advances in Civil Engineering. vol. 2010. DOI:10.1155/2010/194102

**Gustafsson, S.E. (1991)** *Transient plane source techniques for thermal diffusivity measurement of solid materials*. Rev Sci Instrum; vol. 62, no 3, pp. 797-804.

**Jerman, M. – Keppert, M. – Výborný, J. –** Černý, R. **(2013)** *Hygric, thermal and durability properties of autoclaved aerated concrete*. Construction and Building Materials, vol. 41, pp. 352-359. DOI:10.1016/j.conbuildmat.2012.12.036.

**Khodabakhshian, A. – Ghalehnovi, M. – Brito, J.D – Shamsabadi, E.A. (2018)** *Durability performance of structural concrete containing silica fume and marble industry waste powder*. J. Cleaner Prod, vol. 170, pp. 42-60. DOI: 10.1016/j.jclepro.2017.09.116.

**Lian, C.** – **Zhuge, Y.** – **Beecham, S. (2011)** *The relationship between porosity and strength for porous concrete.* Construction and building materials, vol. 25, no 11, pp. 4294-4298. DOI:10.1016/j.conbuildmat.2011.05.005.

**Makhloufi, Z. – Bederina, M. – Bouhicha, M. – Kadri, E.H. (2014)** *Effect of mineral admixtures on resistance to sulfuric acid solution of mortars with quaternary binders*. Phys. Procedia, vol. 55, pp. 329-335. DOI:10.13140/2.1.1599.4568.

**Messaoudene, I.** – **Jauberthie, R.** – **Naceri, A. (2011)** *Influence des fillers de calcite sur le comportement des mortiers au jeune* ***âge****.* Actes des 29ème Rencontre de Génie Civil, 29-31 Mai, Tlemcen-Algérie, pp. 197-205. Available at: https://www.researchgate.net/publication/267725592.

**Mugahed Amran, Y. H.** – **Nima, F. – Abang Ali, A.A. (2015)** *Properties and applications of foamed concrete; a review*. Construct Build Mater, vol. 101, pp. 990-1005. DOI: 10.1016/j.conbuildmat.2015.10.112.

**Munir, M. J. – Kazmi, S. M. S. –Wu, Y.F. (2017)** *Efficiency of waste marble powder in controlling alkali–silica reaction of concrete: A sustainable approach*. Const. Build. Mat, vol. 154, pp. 590-599.

DOI: 10.1016/j.conbuildmat.2017.08.002.

**Nambiar, E. K. – Ramamurthy, K. (2006)** *Influence of filler type on the properties of foam concrete.* Cem. Concr. Compos., vol. 28, no 5, pp. 475-480.DOI:10.1016/j.cemconcomp.2005.12.001.

**Nambiar, E. K. – Ramamurthy, K. (2006)** *Models relating mixture composition to the density and strength of foam concrete using response surface methodology*.Cem.Concr.Compos. vol. 28, no 9, pp. 752-760.

DOI: 10.1016/j.cemconcomp.2006.06.001.

**Narayanan, N.** – **Ramamurthy, K. (2000)** *Structure and properties of aerated concrete: a review*. Cement & Concrete Composites, vol. 22, no 5, pp. 321-329. DOI: 10.1016/S0958-9465(00)00016-0.

**NF EN 18-560 (1990)** *Analyse granulométrique par tamisage, Granulats, AFNOR*.

**NF P 18-598 (Déc. 1981)** *Granulats,Equivalent de sable*.

**Ramamurthy, K.** – **Nambiar, E. K.** –**Ranjani, G. I. S. (2009)** *A classification of studies on properties of foam concrete*, Cem. Concr. Compos. vol. 31, no 6, pp. 388-396. DOI: 10.1016/j.cemconcomp.2009.04.006.

**Richard, A. O.** – **Ramli, M. (2013)** *Experimental production of sustainable lightweight foamed concrete,* Br. J. Appl. Sci. Technol. vol. 3, no 4, pp. 994. DOI:10.9734/BJAST/2013/4242.

**RILEM (1970)** *Commission des bétons légers*.Terminologie et définition. Matériaux et construction N°13, pp.60-69.

**Rilem, L. C. (1978)** *Functional classification of lightweight concretes*, Mater. Struct, vol. 11, pp. 281-283.

**RILEM Recommended Practice. (1993)** *Autoclaved Aerated Concrete: Properties,Testing and Design*. London: Taylor & Francis.

**Shirule, P. A. – Ataur, R. – Gupta Rakesh, D. (2012)** *Partial replacement of cement with marble dust powder*. Int J Adv Eng Res Stud., vol.1, no 3, pp. 2249.

**Sun, F. L. – Wu, S. – Jiang, Q. – Liu, T.T. (2016)** *Study on the Threshold Value and Test Methods for Chloride Ion Content in Sea Sand.* Key Engineering Materials, vol. 680, pp. 482-485.

**Tebbal, N. – Rahmouni, Z. (2016)** *Influence of local sand on the physicomechanical comportment and durability of high performance concrete*. Adv. Civ. Eng., vol. 2016, pp.2-8, DOI: 10.1155/2016/3897064.

**Topcu, IB.** – **Bilir, T.** – **Uygunoglu, T. (2009)** *Effect of waste marble dust content as filler on properties of self-compacting concrete.* Const. Build. Mat., vol. 23, no 5, pp. 1947-1953. DOI:10.1016/j.conbuildmat.2008.09.007.

**Torquato, S. – Haslach Jr, H.W. (2002)** *Random heterogeneous materials: microstructure and macroscopic properties.* Appl. Mech. Rev., vol. 55, no 4, pp. B62-B63. DOI: 10.1115/1.1483342.

**Vardhan, K. – Siddique, R. – Goyal, S. (2019)** *Strength, permeation and microstructural characteristics of concrete incorporating waste marble*. Constr. Build. Mater, vol. 203, pp. 45-55. DOI:10.1016/j.conbuildmat.2019.01.079.