Open Access
Original paper

Budownictwo i Architektura / Civil and Architectural Engineering 25(2) (2026) 26031
https://doi.org/10.35784/bud-arch.8180

Utilisation of bio-based acorn cupule aggregates in producing lightweight concrete: Influence of thermal treatment on performance characteristics

Somia Hamraoui[1], Djamila Boukhelkhal[2], Mohamed Guendouz[3,*]

[1] *Laboratory of Materials and Environment (LME); Faculty of Technology; University of Medea; Medea 26000, Algeria; hamraoui.somia@univ-medea.dz*
[2] *Department of Civil Engineering; Laboratory of Materials and Environment (LME); Faculty of Technology; University of Medea; Medea 26000, Algeria; boukhelkhal.djamila@univ-medea.dz*
[3] *Department of Civil Engineering; Laboratory of Materials and Environment (LME); Faculty of Technology; University of Medea; Medea 26000, Algeria; guendouz.mohamed@univ-medea.dz*

[*] *Corresponding Author*
Received: 01.08.2025; Revised: 18.04.2026; Accepted: 23.04.2026; Available online: 26.06.2026
License: CC-BY 4.0; 2026 Budownictwo i Architektura – Civil and Architectural Engineering

Abstract:
Environmental and climatic challenges necessitate careful consideration and strategic planning regarding the materials and techniques employed across all sectors. To reduce the depletion of non-renewable resources and to improve and achieve sustainable development, researchers have recently become interested in the trend of using bio-based materials as alternative resources in numerous fields. Given that the construction sector poses the main threat to environmental balance due to its high consumption of raw materials, such as fine and coarse aggregates widely used to create different concrete, and energy resources, particularly for building ventilation and cooling, this study aims to use acorn cupule (AC) waste as a low-cost and renewable lightweight bio-aggregate to develop green lightweight flowable sand concrete (FSC) with high insulation properties. Since such organic materials have a negative impact on concrete's mechanical performance, a heat treatment was applied to this AC aggregate to enhance its surface properties. For this purpose, the natural sand was volumetrically substituted with raw and heat-treated acorn cupule aggregates (RAC and HAC) at 10, 20, 30, 40, and 50% in FSC. The results showed that incorporating RAC aggregates decreased the concrete's workability compared to the control one. The density, compressive strength, and flexural strength were reduced by up to 50%, 84%, and 68%, respectively, while the thermal conductivity was improved by approximately 24–89%. The heat treatment of RAC aggregates enhanced FSC flowability; reduced water absorption, reducing concrete porosity by 25%; and significantly improved the compressive and flexural strength by up to 41% and 45%, respectively. However, a slight decline in thermal performance was recorded. Finally, with up to 30% RAC and 40% HAC, AC was proven to be a highly recommended ecological alternative to natural aggregates in the concrete industry for developing lightweight-insulating-structural FSC.

Keywords:
acorn cupule, heat treatment, lightweight concrete, renewable energy, thermal performance

1. Introduction

The world has recently been facing numerous environmental challenges, including the reduction of CO_2 emissions, conservation of natural resources, and reduction of waste storage in landfills [1-3]. Given that the construction sector is the primary threat to environmental balance due to its depletion of raw and energy resources, the latter is increasingly encouraged to use more sustainable and environmentally friendly materials, potentially based on natural and bio-based products, which can be modified to reduce their environmental impact [4,5]. In addition, for energy-effective buildings, the thermal performance of the building has to be improved by the application of advanced building materials [6]. Concrete is the most widely used man-made building material due to its availability, durability, strength, and relatively low cost. Its global production of 25 billion tons annually by 2050 puts significant pressure on the environment [7]. So, using eco-friendly materials would help to curb resource depletion, such as natural aggregates [8,9], which make up 70 to 80% of concrete [10], and improve indoor air quality and energy consumption. Additionally, owing to its lower cost and to legal requirements, this approach also addresses the economic and environmental challenges that many countries face [11].

Lightweight concrete (LWC) is a type of widely used concrete for its low cost, reduced density (less than 2000 kg/m³), improved thermal and acoustic insulation, fire resistance, etc. [12,13]. Due to these advantageous qualities, LWC can be considered a potential alternative to conventional dense concrete [14,15]. The reduced self-weight of lightweight concrete allows for the construction of lighter buildings, which helps save money and materials [14,16]. LWC reduces structural dead loads by up to 35–40% compared to traditional concrete, allowing for smaller foundations, faster construction times, and significant material savings [17]. Extremely porous natural and artificial lightweight aggregates (LA) are often utilized in the manufacturing of LWC [18]. However, these aggregates, which are classified as non-renewable resources with few prospects for future extraction, are only widely accessible in certain regions, making their transportation costly [17,19]. Furthermore, artificial aggregates may be obtained by processing natural materials (e.g., expanded clay); nonetheless, they are frequently coming from industrial wastes and/or by-products (e.g., granulated blast furnace slag, fly ash, plastic waste, and ceramic waste) [20-22]. The main disadvantage connected with the conversion of a dense material into its lightweight form consists in the considerable

consumption of energy. This negative energetic impact may be suppressed by using appropriate industrial wastes and by-products with hidden value.

Agricultural waste and by-products that are generated worldwide in significant amounts on a daily basis, such as rice husk (RH), corn cob (CC), coconut shell (CS), oil palm shell (OPS), bamboo, apricot shell, olive core, coffee waste, and sugarcane bagasse (SCB), have been in focus for quite some time to use as alternative materials, either for cement or for aggregates, to produce green concretes [23-28]. Bio-based aggregates have the benefit of being more readily available, being less expensive than mineral fillers [29], and being able to be used without further processing. The other added values of the use of bio-aggregates are the production of composites with enhanced thermal and/or noise insulation properties [30,31]. Therefore, previous research has been conducted on the possibility of developing environmentally friendly concretes using plant-based construction materials derived from agricultural waste with the aim of reducing the cost and increasing the energy efficiency of concrete [32-37]. However, adding bio-based aggregate to concrete mixes may have a significant detrimental effect on the strength performance and durability of hardened composites due to, e.g., possible biodegradation and the release of natural oils that prevent the bio-aggregate from forming bonds with the cement matrix [38].

Numerous efforts have been made to enhance the mechanical properties of bio-based aggregate concrete to expand its scope of use by applying various processing techniques to plant-based aggregates. Most treatment techniques enhance the surface properties of the aggregate by roughening it while only partially eliminating its organic content (*e.g.*, carbonization, alkalization, and application of lime) [39-41]. This residual organic nature limits compatibility with the cementitious matrix. Furthermore, the hydrophilic behavior of plant-based aggregates adversely affects the interfacial transition zone (ITZ), resulting in increased porosity [42]. This issue has prompted researchers to turn to heat treatment of plant-based aggregates, which completely reduces organic matter and thus minimizes its negative impact on cement hydration. It also reduces water absorption by eliminating hydrophilic groups [43], making the concrete less porous [42,44]. According to Yew et al. [44] and Wu et al. [45], heat treatment roughens the bio-based aggregate surface, reduces its oxygen content, and decomposes its organic matter, thus minimizing its negative impact on cement hydration and decreasing its porosity, as well as improving the ITZ by increasing its bond with the cement matrix [43]. As a result, the mechanical properties of lightweight concrete (LWC) incorporating organic aggregates were enhanced. An improvement in the compressive strength and elastic modulus was also recorded by Yew et al. [40] for LWC incorporating heat-treated oil palm aggregates. Similarly, Wu et al. [45] found that the heat treatment of apricot shell (AS) aggregates increases the flexural and compressive strength by 87.7% and 50.2%, respectively. In another study, Wu et al. [39] also found an increase by 33.8–53.6% in compressive strength of concrete based on heat-treated bio-aggregates compared to concrete with untreated aggregates. Other researchers also illustrated similar results for thermally treated and untreated palm oil fuel ash and sugarcane bagasse ash blended concrete [46,47].

Flowable sand concrete (FSC) is one of the innovative concretes, defined as concrete that combines the qualities of sand concrete with sufficient fluidity to function well in current civil engineering structures [48,49]. It is distinguished by its simplicity of installation and lack of compaction [50,51]. Its highly flowable ability makes it supreme for complicated and congested structures and allows for quicker production with minimal noise and labor. This type of concrete provides innovative solutions for the construction industry due to its effectiveness and adaptability in different applications, such as deep foundation construction, soil grouting, and concrete restoration [18]. Typically, FSC is rich in fine aggregates (sand) and free from coarse aggregates (gravel). It is composed of sand, cement, water, one or more admixtures, and additives [52].

Acorn cupule wastes (AC) are another agriculture byproduct existing in huge quantities in forest areas, especially in Mediterranean countries like Algeria. Oak species, including *Quercus suber* and *Quercus ilex*, cover roughly 40% of Algeria's forests (357231 ha), with an annual production of over 15000 tonnes, playing a vital role in ecological, social, and food systems, and can be a source of environmental pollution [53]. AC has a lower specific gravity compared to conventional aggregates, resulting in lightweight concrete with reduced self-weight. Several studies have been carried out on examining the possibility of substituting fine or coarse aggregate with different vegetable wastes in mortar and ordinary concrete. However, no research has been done until now on the use of AC as aggregate components in flowable sand concrete (FSC), which may be due to the lack of clear information on standard requirements and quality control that will guarantee AC's efficacy and long-term use in the manufacturing of high-quality concrete. Hence, this study aims to recover and valorize raw AC (RAC) waste as lightweight aggregate to create a new flowable LWC based on renewable materials. As well as to study the effect of heat treatment mode for this plant waste on the physicomechanical and thermal properties of FSC. For this, the natural sand was substituted by RAC and HAC at replacement ratios of 10%, 20%, 30%, 40%, and 50%. The workability, density, porosity, compressive and flexural strength, porosity, and thermal conductivity of RAC and HAC-based FSC are analyzed and compared to those for the control FSC. Scanning electron microscope (SEM) analysis was also performed to assess the microstructure of RAC and HAC aggregates, as well as FSC-RAC and FSC-HAC mixtures.

2. Materials and methods

2.1. Materials

2.1.1. Cement and filler

Marble powder waste (MPW) and CEM II/B 42.5 cement (MATINE) were used as a binder with an MPW/Cement ratio of 0.5. Superplasticizer "ViscoCrete - 4037 RMX" and drinking water were used. The physical properties of cement and MPW used in this study are illustrated in Table 1.

2.1.2. Natural and recycled aggregates

Natural sand from the Oued Souf quarry (Oued Souf city, Algeria) was used as fine aggregate in this study. Raw acorn cupules (RAC) and heat-treated acorn cupules (HAC) are used to partially replace natural sand in volume (Fig. 1). The acorn cupules were initially crushed and then sieved to obtain aggregates with a maximum size of 3.15 mm. For preparing HAC, the RAC aggregates were soaked in water for 24 hours and then air-dried until reaching a saturated surface-dry condition [39,54,55]. After that, they were preheated at 200°C for 0.5–1 hour, followed by pyrolysis at temperatures ranging from 350 to 550°C for 4 hours (corresponding to the pyrolysis temperature of lignin). Finally, the HACs were cooled down to ambient

temperature [39,45]. Figure 2 presents the SEM images of RAC and HAC aggregates. The particle size distributions of sand and RAC aggregate used are shown in Fig. 3. The physical properties of natural and recycled aggregates used in this study are illustrated in Table 1.

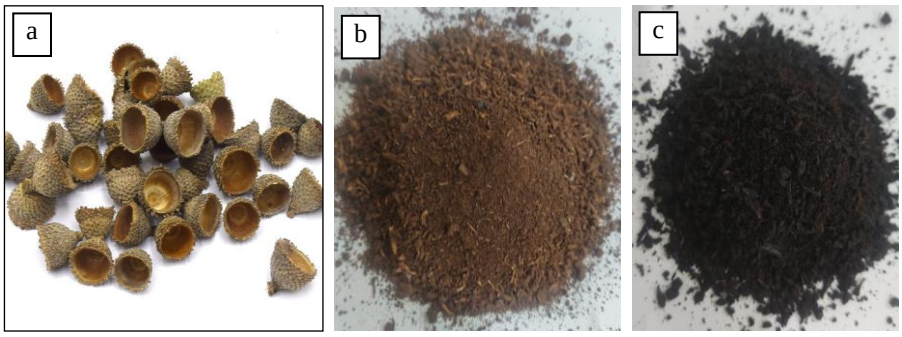

Fig. 1. Photographic image of a/ acorn cupules; b/ crushed acorn cupules; c/ heat-treated crushed acorn cupules. Source: own study

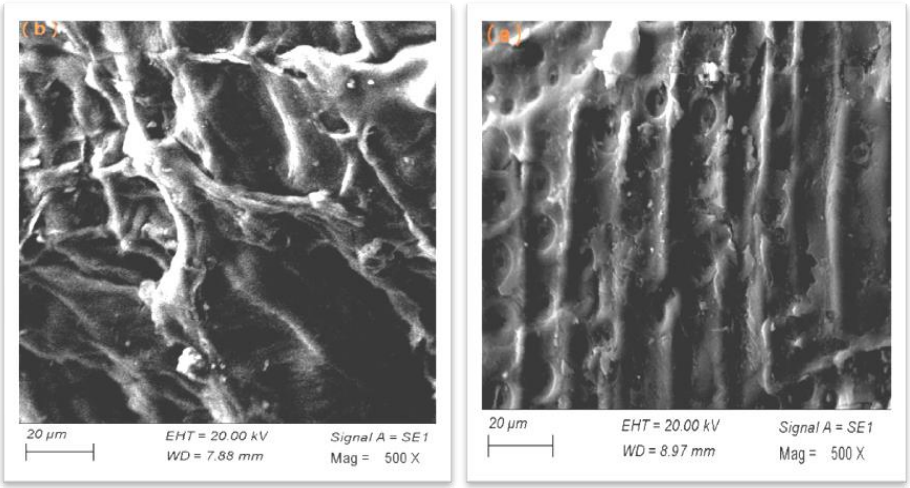

Fig. 2. SEM images of (a) RAC aggregates and (b) HAC aggregates. Source: own study

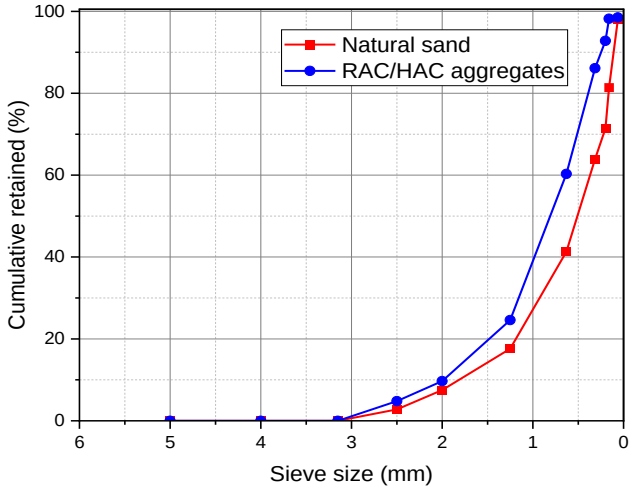

Fig. 3. Particle size distribution of natural sand and crushed acorn cupules. Source: own study

Table 1. Physical characteristics of cement, MWP, natural sand, RAC, and HAC aggregates. Source: own study

Physical properties	Cement	MPW	Sand	RAC	HAC
Particle size (mm)		< 0.08	< 4	< 3.15	< 3.15
Density (g/cm^3)	3.11	2.84	2.63	0.62	0.51
Blaine fineness (cm^2/g)	3420	2300	-		-
Fineness modulus	-	-	2.07	2.74	2.74
Water absorption (%)	-	-	0.2	96.25	64.34

MPW – Marble powder waste; RAC – Raw acorn cupules; HAC - Heat-treated acorn cupules

2.2. Mix proportions of concrete

Flowable sand concrete (FSC) defined in accordance with the SABLOCRETE project [56] is used as a control mix [57]. Ten other FSC mixes were prepared by replacing natural sand at 10, 20, 30, 40, and 50% in volume by RAC or HAC aggregate. For all FSC mixes, the water-to-binder ratio (w/b) was kept constant at 0.44, and the sand-to-mortar ratio (S/M) was at 0.5, with varying rates of superplasticizer in order to achieve slump flow ranges of 28±1 cm in accordance with the EFNARC recommendations [58]. The mix proportions of different FSC mixes are presented in Table 2.

2.3. Testing procedures

Firstly, the fresh properties of all prepared FSC mixes were tested before casting them into oiled moulds. The hardened mixture properties, along with the physical, thermal, and mechanical characteristics, were also assessed in the present study in accordance with the standards outlined in Table 3. Additionally, a scanning electron microscope (SEM) was used to examine the morphological microstructure and to support the interpretation of certain results.

Table 2. Mix proportioning of different FSC mixes. Source: own study

Mix	Binder		Fine aggregate			w/b ratio	S_P (%)
	Cement (Kg/m^3)	MWP (Kg/m^3)	Sand (Kg/m^3)	RAC (Kg/m^3)	HAC (Kg/m^3)		
Control	400	200	1400	-	-	0.44	0.7
FSC-RAC_{10}	400	200	1260	33.00	-	0.44	0.8
FSC-RAC_{20}	400	200	1120	66.00	-	0.44	0.9
FSC-RAC_{30}	400	200	980	99.01	-	0.44	1.0
FSC-RAC_{40}	400	200	840	132.01	-	0.44	1.1
FSC-RAC_{50}	400	200	700	165.01	-	0.44	1.2
FSC-HAC_{10}	400	200	1260	-	27.15	0.44	0.7
FSC-HAC_{20}	400	200	1120	-	54.97	0.44	0.8
FSC-HAC_{30}	400	200	980	-	81.54	0.44	0.9
FSC-HAC_{40}	400	200	840	-	108.60	0.44	0.9
FSC-HAC_{50}	400	200	700	-	135.74	0.44	1.0

MPW – Marble powder waste; RAC – Raw acorn cupules; HAC - Heat-treated acorn cupules; w/b – water-to-binder ratio, SP – Superplasticizer.

Table 3. Experimental tests applied to determine the physical and mechanical properties of different FSC mixes. Source: own study

Test	Age	Mold dimensions	Standard
Fresh state			
Slump flow		(70×100×60 mm)	EFNARC [58]
Hardened state			
Density	28 days	(75×75×280 mm)	ASTM C567-19 [59]
Porosity	28 days	½ (40×40×160 mm)	ASTM C642-21 [60]
Thermal conductivity	28 days	(75×75×280 mm)	NF EN 993-15 [61]
Compressive and flexural strength	7, 28, and 90 days	(40×40×160 mm)	EN 196-1 [62]

3. Results and discussion

3.1. Workability of fresh FSCs

Figure 4 displays the workability outcomes of the different FSC mixes as a function of superplasticizer need with regard to a slump flow value of 28±1 cm. Compared to the control FSC, this figure shows an increase in the superplasticizer requirement of FSC mixes incorporating RAC aggregate (FSC-RAC) with increasing RAC content. The partial replacement of 50% natural sand with RAC aggregates increases by about 71% the superplasticizer need of sand concrete mixtures. This increase in superplasticizer need indicates a decrease in workability, which can be attributed to the high water absorption and the lower surface quality of the plant-based RAC aggregate according to Inoue et al. [43] and Guermiti et al. [63].

After the heat treatment, the workability of FSC incorporating HAC aggregate (FSC-HAC) was enhanced compared to the FSC-RAC mixes. This enhancement is reflected by the reduced need for superplasticizer to maintain the previously defined workability. This improvement in the flow of HAC-based FSC can be explained by the reduction of hydroxyl groups of the HAC aggregate, thereby reducing its water absorption [44], which allows a portion of the water to be redirected towards hydration [43]. This beneficial impact of heat treatment on workability has also been observed in other investigations [43-45]. Those also demonstrated that this positive effect increases with increasing temperature and duration of treatment.

3.2. Dry density, thermal conductivity, and porosity of hardened FSCs

The dry density and thermal conductivity as well as the porosity results of the different FSC mixes, are displayed in Fig. 5 and Fig. 6, respectively. Compared with the control FSC, the dry density of FSC decreases by around 12 to 50% with increasing RAC content, which is attributed to the low density of

RAC aggregate compared to natural sand as well as to the honeycomb porous structure of RAC aggregates (Fig. 2(a)), resulting in an increase in the number of voids in the cement matrix, as shown in Fig. 7. This is also confirmed by the effective porosity values illustrated in Fig. 6 and those obtained in the study of Charai et al. [64]. Besides, the high water absorption of RAC may affect the ITZ and increase its porosity (Fig. 7) [42,65].

Furthermore, the heat treatment of RAC aggregate led to a decrease of 7 to 10% in the density of FSC-HAC mixes compared to FSC-RACs, which may be attributed to the lower weight of HAC aggregate compared to RAC aggregate. This loss in concrete density due to the reduction in the weight of the plant-based aggregate under the effect of this treatment was also stated in other studies [45,66]. In addition, Fig. 6 shows that the heat treatment reduces the porosity of FSC-HACs by approximately 25% in comparison with FSC-RACs due to the pyrolysis temperature, which minimizes the pore size of bio-based materials as reported by Nakanishi et al. [67]. This result is in line with previous studies [44,68]. Similarly, Wu et al. [69] found a 9.6% reduction in the porosity of mortar with heat-treated miscanthus and justified this by the good compatibility between the miscanthus and the mortar, which reduced the microporous structure in the ITZ. In another investigation, a decrease of 24% in the porosity of heat-treated miscanthus mortar was observed [70].

The thermal conductivity results presented in Fig. 5 indicate an increase in thermal performance with the increase of RAC aggregate content, as observed by a 24 to 89% decrease in thermal conductivity compared to the control FSC. This enhancement in the thermal performance of RAC-based FSC is probably due to the porous structure of RAC aggregates, the weak interfacial transition zone (ITZ) acting as an insulator, and the high porosity of FSC-RACs [68]. This result has also been observed in other studies incorporating bio-based aggregates in concrete [57,71,72]. On the other hand, heat treatment of RAC aggregates affected the thermal performance of FSCs by increasing their thermal conductivity by 12–20% compared to RAC-based FSCs, which may be due to the reduction in porosity of both HAC aggregates and FSC-HAC mixes.

Based on the dry density and thermal conductivity (λ) values and according to RILEM classification [73], the incorporation of more than 20% of RAC/HAC aggregates leads to developing lightweight concrete (LWC) with a density and λ values below 2000 kg/m^3 and 1 W/m.K, respectively.

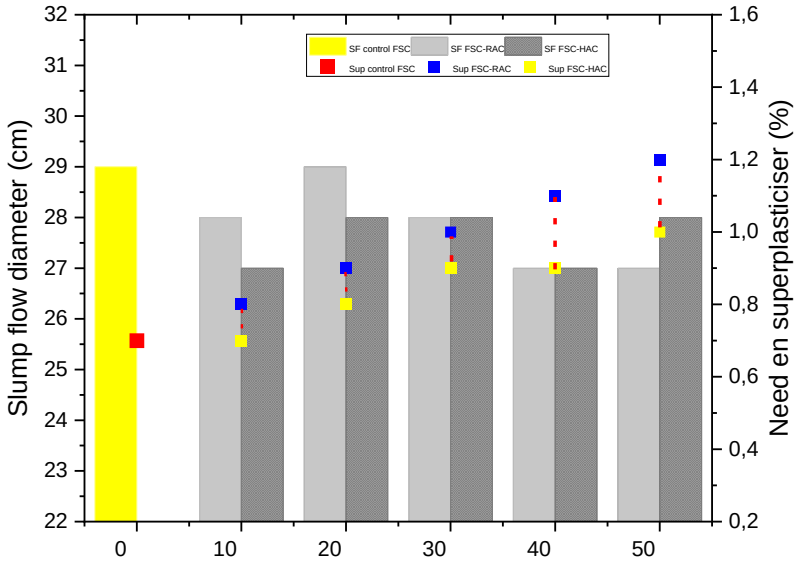

Fig. 4. Slump flow and need for superplasticizer of all FSC mixes. Source: own study

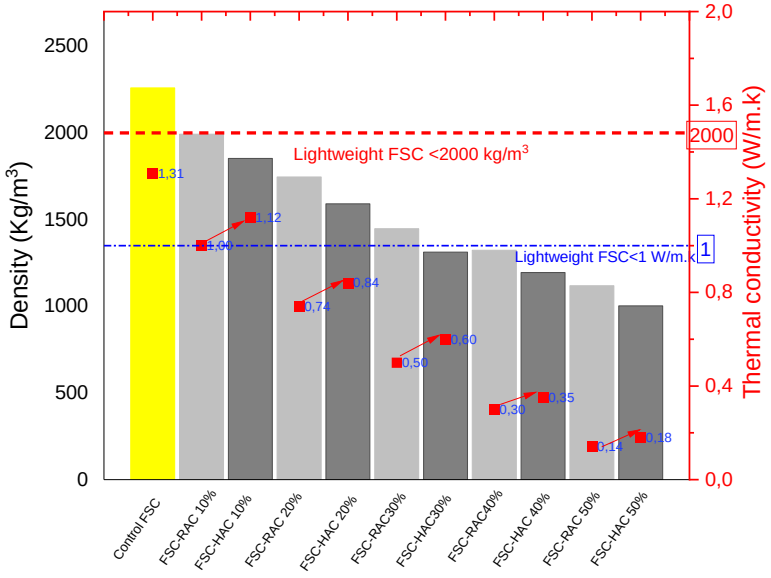

Fig. 5. Dry density and thermal conductivity of FSC mixes at 28 days. Source: own study

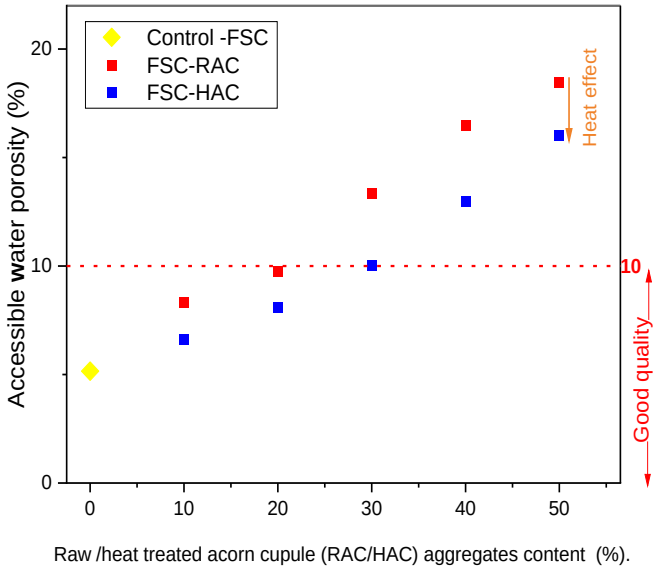

Fig. 6. Accessible water porosity of FSC mixes at 28 days. Source: own study

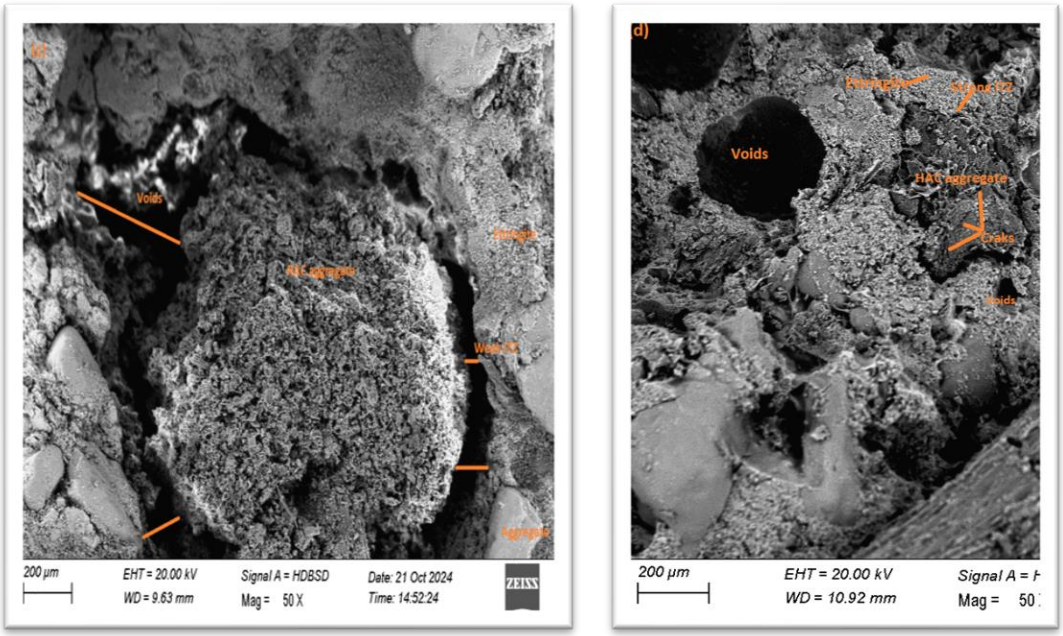

Fig. 7. SEM images of (a) FSC-RAC (b) FSC-HAC mixes. Source: own study

3.3. Compressive and flexural strengths of hardened FSCs

Figures 8 and 9, respectively, show the compressive and flexural strength results at 7, 28, and 90 days for all FSCs. Compared with the control FSC, these results indicate that both compressive and flexural strengths decreased significantly with increasing RAC aggregate content. A 37-84% and 24-68% reduction was observed at 28 days for the compressive and flexural strength, respectively. This reduction in both mechanical strengths can be attributed to the weak bond between the RAC aggregates and the cementitious matrix, with the presence of cracks in the ITZ of the FSC-RAC mixtures resulting from the low strength and smooth surface texture of the RAC aggregates compared to natural sand [69,74-76]. Furthermore, Wu et al. [55] attributed the decrease in strength to the organic effect of plant-based materials, which exerts a retarding influence on cement hydration.

Furthermore, it is also demonstrated from Fig. 8 and Fig. 9 that the heat treatment of RAC aggregate has greatly enhanced the mechanical strengths of FSC compared to FSC-RAC mixes. An increase of 18 to 45% and 12 to 41% was observed at 28 days for the compressive and flexural strength, respectively, for FSC-HACs compared to FSC-RAC with the same substitution rate of natural sand. This improvement in mechanical strength resulted from the roughness of the HAC aggregate surface compared to RAC, as shown in Figs. 2(a) and 2(b), which led to a good bond in ITZ between the HAC aggregate and cementitious matrix, as shown in Fig. 7. This positive effect of heat treatment on strength improvement was also highlighted in other previous studies [39,44]. Wu et al. [69] found an increase of 82.7% and 26.9% at 28 days in compressive and flexural strength, respectively, and attributed this to the removal of sugars from the biomass as a result of pyrolysis, which led to greater adhesion. In another study, Wu et al. [45] found a 50.2% and 87.7% increase in compressive and flexural strength, respectively, and linked this improvement to the decomposition of organic matter in heat-treated bio-based aggregate, thus reducing its negative effects on the strength of concrete. According to Rosales et al. [77], by

applying heat-treatment processes to biomass bottom ash (BBA), an increase of 80% in the compressive strength of the mortars is achieved for 20% substitution compared to untreated processed BBA mortars.

According to the American Institute classification (Table 4) and based on the obtained compressive strength results, FSC-RAC 10% and FSC-HAC 10–20% mixtures can be classified as structural concrete, while FSC-RACs 20–50% and FSC-HACs 30–50% fall under the category of moderate-strength concrete. Given that all the designed mixtures incorporating either raw or treated acorn cupule aggregates exhibit densities below 2000 kg/m³, they can be classified according to RILEM classification [73] as lightweight structural concrete (FSC-RAC 10 and FSC-HAC 10–20%) and lightweight insulating/structural concrete (FSC-RACs 20–50% and FSC-HACs 30–50%), respectively.

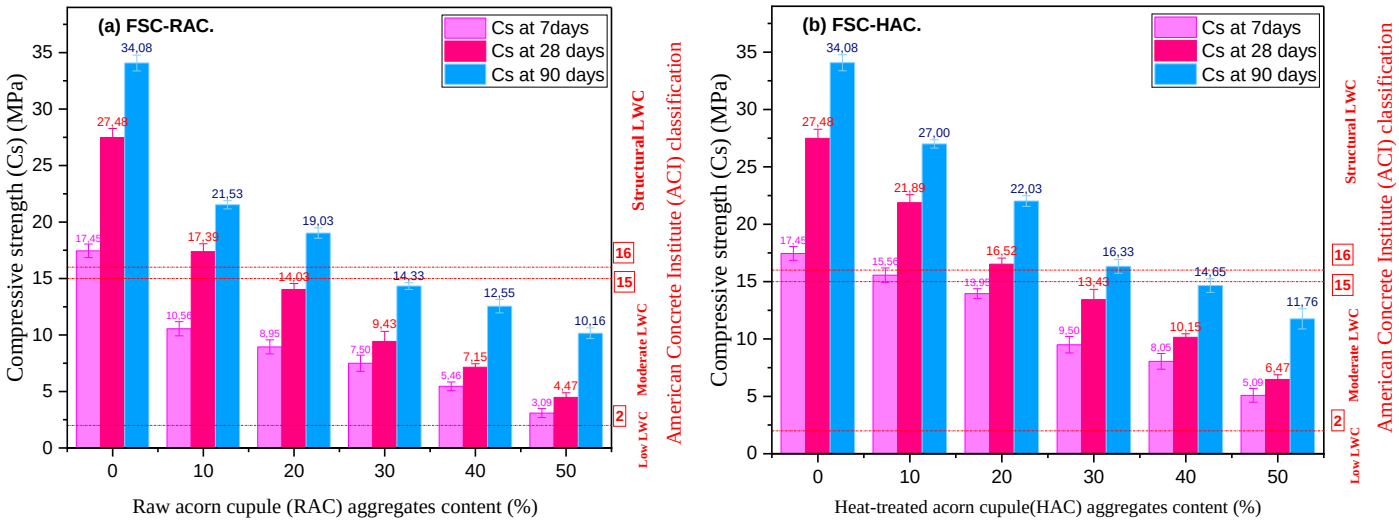

Fig. 8. Compressive strength of (a) FSC-RACs and (b) FSC-HACs mixes. Source: own study

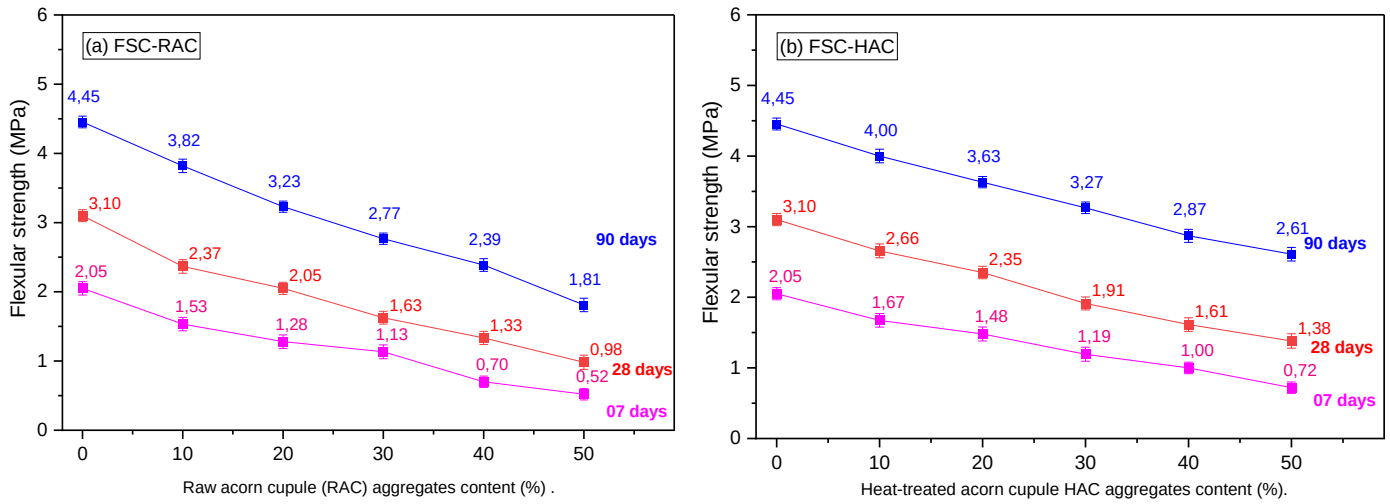

Fig. 9. Flexular strength of (a) FSC-RACs and (b) FSC-HAC mixes. Source: own study

Table 4. RILEM classification of LWC based on thermal conductivity (λ) measurements. Source: [73]

λ (W/m·K)	λ < 0,35	0,35 < λ < 0,75	0,75 < λ
RAC aggregates content (%)	40 and 50	20,30.	10.
HAC aggregates content (%)	50	30,40.	10,20.
Classification of LWC	Insulating	Insulating /structural	Structural

4. Conclusion

This study was conducted to investigate the possibility of recycling acorn cupule (AC) as a plant-based raw material for developing a new bio-based lightweight flowable sand concrete (LWFSC) and to reduce the impact of its organic matter on the physical and mechanical properties of concrete through heat treatment. Based on the obtained results, the following conclusions are formally established:

1. The valorization of acorn cupule as fine aggregates reduces the physical and mechanical properties of lightweight flowable sand concrete due to their organic nature, porous structure, and surface morphology.
2. Replacing sand with AC reduces the workability of FSC mixtures, resulting in a higher need for superlasticizer concentration, which can be attributed to the high-water absorption and the lower surface quality of the plant-

based RAC aggregate. The use of 50% RAC aggregates as natural sand leads to about a 71% increase in superplasticizer need. However, heat treatment of these aggregates shows an enhancement in the flowability of FSC-HAC compared to the FSC-RAC mixes, likely due to the improved surface quality and reduced water absorption of the treated aggregates.

3. The increase in RAC aggregates content decreases the early and later age mechanical strengths of FSC mixes. A reduction of approximately 84% and 68% in 28 days compressive and flexural strength was found, respectively, by adding 50% RAC aggregates compared to the control FSC. However, these results are acceptable in the case of lightweight concrete.
4. The dry density of FSC decreases by around 12 to 50% with increasing RAC content, which is attributed.
5. Densities the heat treatment reduces the porosity of FSC-HACs by approximately 25% in comparison with FSC-RACs due to the pyrolysis temperature, which minimizes the pore size of bio-based materials.
6. The developed lightweight FSC based on eco-friendly AC aggregates exhibits excellent thermal insulation, with thermal conductivity values ranging from 0.14 W/mK to 1 W/mK.
7. The heat treatment of RAC aggregates affects the thermal insulation performance of FSC mixes by increasing the thermal conductivity by 12–20%. However, the compressive and flexural strengths were significantly improved by 18–45% and 12–41%, respectively. This enhancement in mechanical properties is attributed to the better interfacial bonding with the mortar and reduced voids of HAC-based FSC, resulting from the rough surface and low porosity of the heat-treated AC aggregates.
8. Given that all the designed mixtures incorporating either raw or treated AC aggregates exhibit densities below 2000 kg/m³, they can be classified as lightweight structural concrete (FSC-RAC 10 and FSC-HAC 10–20%) and lightweight insulating/structural concrete (FSC-RACs 20–50% and FSC-HACs 30–50%), respectively.

Indeed, the acquired results, considering the density, mechanical properties, and thermal conductivity, are very encouraging and indicate the possibility of using AC as a suitable alternative bio-aggregate material for insulation in buildings. Moreover, from a cost perspective, using SCG waste in concrete does not require additional costs to produce lightweight concrete compared to other insulation materials. With up to 20% AC, the obtained new FSC based on AC waste is highly recommended for many structural components manufactured for building construction. Comparing untreated and treated AC, the findings indicate that heat treatment of AC aggregates can significantly enhance bonding with cementitious materials, thereby improving the overall performance of the mixtures.

Finally, recycling of AC waste as fine bio-aggregate, together with local materials in the production of construction material, is a reasonable solution to the problems of resource conservation, natural pollution, and energy saving for future generations. Since ACs are plant waste, we found it necessary to investigate the long-term durability behaviour of the studied FSC concretes (in progress), including bond strength, creep and shrinkage, sorptivity, and corrosion. These properties were not considered in our study, so further research in this area is needed for future work.

References

[1] Guendouz M., Boukhelkhal Dj., Physical and mechanical properties of cement mortar made with brick waste. *MATEC Web of Conferences* 149 (2018) 01077. https://doi.org/10.1051/matecconf/201814901077

[2] Alsharari F., Utilization of industrial, agricultural, and construction waste in cementitious composites: A comprehensive review of their impact on concrete properties and sustainable construction practices. *Materials Today Sustainability* 29 (2025) 101080. https://doi.org/10.1016/j.mtsust.2025.101080

[3] Hadjadj M., Guendouz M., Boukhelkhal Dj., The effect of using seashells as cementitious bio-material and granite industrial waste as fine aggregate on mechanical and durability properties of green flowable sand concrete. *Journal of Building Engineering* 87 (2024) 108968. https://doi.org/10.1016/j.jobe.2024.108968

[4] Guendouz M., Boukhelkhal Dj., Triki Z., Mechantel A., Boukerma T., Effect of using spent coffee grounds wastes as aggregates on physical and thermal properties of sand concrete. *Algerian Journal of Environmental Science and Technology* 9(3) (2023) 3256 – 3264.

[5] Benimam S., Debieb F., Bentchikou M., Guendouz M., Valorisation et Recyclage des Déchets Plastiques dans le Béton. *MATEC Web of Conferences* 11 (2014) 01033. https://doi.org/10.1051/matecconf/20141101033

[6] Ben Hadj Tahar D., Triki Z., Guendouz, M., Tahraoui H., Zamouche M., Kebir M., Zhang J., Amrane A., Characterization and Thermal Evaluation of a Novel Bio-Based Natural Insulation Material from Posidonia oceanica Waste: A Sustainable Solution for Building Insulation in Algeria. *Chem Engineering* 8(1) (2024) 18. https://doi.org/10.3390/chemengineering8010018

[7] Adesina A., Recent advances in the concrete industry to reduce its carbon dioxide emissions, *Environmental Challenges* 1 (2020) 100004. https://doi.org/10.1016/J. ENVC.2020.100004

[8] Guendouz M., Boukhelkhal Dj., Properties of flowable sand concrete containing ceramic wastes. *Journal of Adhesion Science and Technology* 33 (2019) 2661-2683. https://doi.org/10.1080/01694243.2019.1653594

[9] Hadjadj M., Guendouz M., Boukhelkhal Dj., Durability assessment of bio-based self-compacting sand concrete with recycled granite aggregate waste against chloride and sulphate attacks. *Budownictwo i Architektura* 24(2) (2025) 075-094. https://doi.org/10.35784/bud-arch.6797

[10] Yew M.K., Yew M.C., Beh J.H., Saw L.H., Lim S.K., Effects of pre-treated on dura shell and tenera shell for high strength lightweight concrete. *Journal of Building Engineering* 42 (2021) 102493. https://doi.org/10.1016/j.jobe.2021.102493

[11] Hadjadj M., Guendouz M., Boukhelkhal Dj., Enhancing the mechanical and durability properties of bio self-compacting sand concrete containing granite industrial waste as a fine aggregate: an experimental study. *Budownictwo i Architektura* 24(3) (2025) 79-99. https://doi.org/10.35784/bud-arch.7486

[12] Jafari S., Mahini S.S., Lightweight concrete design using gene expression programing. *Construction and Building Materials* 139 (2017) 93-100. https://doi.org/10.1016/j.conbuildmat.2017.01.120

[13] Boukhelkhal Dj., Guendouz M., Triki Z., Physical and thermal properties of lightweight self-compacting mortar made with recycled walnut shells as fine aggregates. *Algerian Journal of Environmental Science and Technology* 9(3) (2023) https://www.aljest.net/index.php/aljest/article/view/898

[14] Jing Y., Chai Lee J., Chek Moon W., Jing L.N., Yew M.K., Chu M.Y., Li B., Comprehensive review on nanomaterials incorporated in lightweight concrete. *Journal of Engineering Research* 14(1) 2026, 69-82. https://doi.org/10.1016/j.jer.2025.06.007

[15] Kumar A.H., Hashwin K., Karthikeyan K., Eco-efficient light weight concrete with agro-waste aggregates and natural fibers: A

sustainability approach. *Construction and Building Materials* 501 (2025) 144387. https://doi.org/10.1016/j.conbuildmat.2025.144387

[16] Shahzad Aslam H.M., Ur Rehman A., Onyelowe K.C., Noshin S., Yasin M., Adil Khan M., Latif A., Usman Aslam H.M., Hussain S., Evaluating the mechanical and durability properties of sustainable lightweight concrete incorporating the various proportions of waste pumice aggregate. *Results in Engineering* 24 (2024) 103496. https://doi.org/10.1016/j.rineng.2024.103496

[17] Behera D., Liu K.Y., Rachman F., Worku A.M., Innovations and Applications in Lightweight Concrete: Review of Current Practices and Future Directions. *Building* 15(12) (2025) 2113. https://doi.org/10.3390/buildings15122113

[18] Kumar P., Pasla D., Jothi Saravanan T., Self-compacting lightweight aggregate concrete and its properties: A review. *Construction and Building Materials* 375 (2023) 130861. https://doi.org/10.1016/j.conbuildmat.2023.130861

[19] Pokorný J., Ševčík R., Šál J., Fiala L., Zárybnická L., Podolka L., Bio-based aggregate in the production of advanced thermal-insulating concrete with improved acoustic performance. *Construction and Building Materials* 358 (2022) 129436. https://doi.org/10.1016/j.conbuildmat.2022.129436

[20] Guendouz M., Debieb F., Boukendakdji O., Kadri E.H., Bentchikou M., Soualhi H., Use of plastic waste in sand concrete. *Journal of Materials and Environmental Science* 7 (2016) 382-389. https://www.jmaterenvironsci.com/Journal/vol7-2.html

[21] Blaifi H., Guendouz M., Belhadj A.E., Boukhelkhal D., Hadjadj M., Sustainable use of recycled plastic and ceramic industrial wastes in eco-freindly construction materials. *Environmental Engineering & Management Journal (EEMJ)* 22(8) (2023). https://doi.org/10.30638/eemj.2023.124

[22] Guendouz M., Boukhelkhal Dj., Bourdot A., Recycling of floor tile waste as fine aggregate in flowable sand concrete. *Advances in Green Energies and Materials Technology* (2021) 223-229. https://doi.org/10.1007/978-981-16-0378-5_30

[23] Lin Y., Alengaram U.J., Ibrahim Z., Effect of treated and untreated rice husk ash, palm oil fuel ash, and sugarcane bagasse ash on the mechanical, durability, and microstructure characteristics of blended concrete – A comprehensive review. *Journal of Building Engineering* 78 (2023) 107500. https://doi.org/10.1016/j.jobe.2023.107500

[24] Loh L.T., Yew M.K., Yew M.C., Beh J.H., Lee F.W., Lim S.K., Kwong K.Z., Mechanical and Thermal Properties of Synthetic Polypropylene Fiber–Reinforced Renewable Oil Palm Shell Lightweight Concrete. *Materials* 14 (2021) 2337. https://doi.org/10.3390/ma14092337

[25] Alsharari F., Utilization of industrial, agricultural, and construction waste in cementitious composites: A comprehensive review of their impact on concrete properties and sustainable construction practices. *Materials Today Sustainability* 29 (2025) 101080. https://doi.org/10.1016/j.mtsust.2025.101080

[26] Asad A., Al-Alwan K., Al-Bazoon M., Mussa F.I., Alalwan H.A., Shadhar M.H., Mohammed M.M., Mohammed M.F., The impact of using rice husk ash as a replacement material in concrete: An experimental study. *Journal of King Saud University – Engineering Sciences* 36(4) (2024) 249-255. https://doi.org/10.1016/j.jksues.2022.03.002

[27] Ahmad J., Moafak Arbili M., Alabduljabbar H., Deifalla A.F., Concrete made with partially substitution corn cob ash: A review. *Case Studies in Construction Materials* 18 (2023) e02100. https://doi.org/10.1016/j.cscm.2023.e02100

[28] Ghavami K., Bamboo as reinforcement in structural concrete elements. *Cement and Concrete Composites*, 27 (6) (2005) 637–649, https://doi.org/10.1016/j.cemconcomp.2004.06.002

[29] Yong Z.C., Yew M.K., Yew M.C., Beh J.H., Lee F.W., Lim S.K., Saw L.H., Utilizing bio-based and industrial waste aggregates to improve mechanical properties and thermal insulation in lightweight foamed macro polypropylene fibre-reinforced concrete. *Journal of Building Engineering* 91 (2024) 109588. https://doi.org/10.1016/j.jobe.2024.109588

[30] Chinnu S.N., Minnu S.N., Bahurudeen A., Senthilkumar R., Reuse of industrial and agricultural by-products as pozzolan and aggregates in lightweight concrete. *Construction and Building Materials* 302 (2021) 124172, https://doi.org/10.1016/j.conbuildmat.2021.124172

[31] Guendouz M., Boukhelkhal Dj., Physical, mechanical and thermal properties of Crushed Sand Concrete containing Rubber waste. *MATEC Web of Conferences* 149., (2018) 01076. https://doi.org/10.1051/matecconf/201814901076

[32] Avellaneda A. Evon P., Haurie L., Laborel-Préneron A., Lagouin M., Magniont C., Navarro A., Palumbo M., Torres A., Evaluation of the Potential of Plant Aggregates from Corn and Sunflower Stalks for the Design of Building Materials, In: Amziane, S., Merta, I., Page, J. (eds) Bio-Based Building Materials. ICBBM 2023. RILEM Bookseries, 45. Springer, Cham., 2023, 70-86. https://doi.org/10.1007/978-3-031-33465-8_7

[33] Yousheng D., Keqin Z., Wenjie L., Qian S., Erli M., Advances in the application of crop residues as aggregates and cementing materials in concrete. *Journal of Material Cycles and Waste Management* 25(2) (2023) 785-792. https://doi.org/10.1007/s10163-023-01605-y

[34] Guendouz M., Boukhelkhal Dj., Properties of dune sand concrete containing coffee waste. *MATEC Web of Conférences* 149 (2018) 01039. https://doi.org/10.1051/matecconf/201814901039

[35] Alcivar-Bastidas S., Petroche D.M., Cornejo M.H., Martinez-Echevarria M., Effect of aging process on mechanical performance of reinforced mortar with NaOH abaca fibers. *Case Studies in Construction Materials* 20 (2024) e03122. https://doi.org/10.1016/j.cscm.2024.e03122

[36] Boukhelkhal Dj., Guendouz M., Bourdot A., Cheriet H., Messaoudi K., Elaboration of bio-based building materials made from recycled olive core. *MRS Energy & Sustainability* 8 (2021) 98-109. https://doi.org/10.1557/s43581-021-00006-8

[37] Guendouz M., Boukhelkhal Dj., Mechantel A., Boukerma T., Valorization of coffee waste as bio-aggregates in crushed sand concrete production. *Environmental Engineering and Management Journal* 22(1) (2023) 147-156. http://doi.org/10.30638/eemj.2023.013

[38] Wu F., Yu Q., Liu C., Brouwers H.J.H., Wang L., Effect of surface treatment of apricot shell on the performance of lightweight bio-concrete. *Construction and Building Materials* 229 (2019), 116859, https://doi.org/10.1016/j.conbuildmat.2019.116859

[39] Wu F., Liu C., Zhang L., Lu Y., Ma y., Comparative study of carbonized peach shell and carbonized apricot shell to improve the performance of lightweight concrete. *Construction and Building Materials* 188 (2018) 758-771 https://doi.org/10.1016/j.conbuildmat.2018.08.094

[40] Yew M.K., Yew M.C., Beh J.H., Lee F.W., Lim S.K., Lee Y.L., Lim J.H., Kabeer K.I.S.A., Effect of Pre-Soaking Treatment Method of Plant-Based Aggregate on the Properties of Lightweight Concrete – Preliminary Study. *Coatings* 13 (2023) 864. https://doi.org/10.3390/coatings13050864

[41] Yew M.K., Beh J.H., Yew M.C., Lee F.W., Saw L.H., Lim S.K., Performance of surface modification on bio-based aggregate for high strength lightweight concrete. *Case Studies in Construction Materials* 16 (2022) e00910. https://doi.org/10.1016/j.cscm.2022.e00910

[42] Lo T.Y., Cui H., Tang W., Leung W.M., The effect of aggregate absorption on pore area at interfacial zone of lightweight concrete. *Construction and Building Materials* 22(4) (2008) 623-628. https://doi.org/10.1016/j.conbuildmat.2006.10.011

[43] Inoue M., Norimoto M., Tanahashi M., Rowell R.M., Steam or heat fixation of compressed wood. *Wood and Fiber Science* 224-235 (1993) 224-235.

[44] Yew M.K., Yew M.C., Saw L.H., Lim S.K., Beh J.H., Ng T.C., Enhancement of durability properties and drying shrinkage of heat-treated oil palm shell species high-strength lightweight concrete. *Nanoscience and Nanotechnology* 2(1) (2018) 1-11.

[45] Wu F., Yu Q., Liu C., Durability of thermal insulating bio-based lightweight concrete: understanding of heat treatment on bio-aggregates. *Construction and Building Materials* 269 (2021) 121800. https://doi.org/10.1016/j.conbuildmat.2020.121800

[46] Li Y., Chai J., Wang R., Zhang X., Si Z., Utilization of sugarcane bagasse ash (SCBA) in construction technology: a state-of-the-art review. *Journal of Building Engineering* 56 (2022) 104774, https://doi.org/10.1016/j.jobe.2022.104774

[47] Rajesh C., Sameer G.N., Maheswar Reddy M.S., Kumar Jagarapu D.C., Jogi P.K., Consumption of palm oil fuel ash in producing lightweight concrete. *Materials Today: Proceedings* 33 (2020) 1073–1078, https://doi.org/10.1016/j.matpr.2020.07.096

[48] Beladzar Z., Boukhelkhal Dj., Guendouz M., Hadjadj M., Contribution to the reinforcement of cement composites using aggregates from industrial windshield waste. *Budownictwo i Architektura – Civil and Architectural Engineering* 25(1) (2026) 26013. https://doi.org/10.35784/bud-arch.8090

[49] Hadjadj M., Guendouz M., Boukhelkhal Dj., Developing High-strength, Flowable Sand Concrete by Adding Combined Industrial Ceramic and Granite Waste with Seashell Bio-waste as Fine Aggregates. *Periodica Polytechnica Chemical Engineering* (2026) 1-12. https://doi.org/10.3311/PPch.42036

[50] Boukhelkhal Dj., Guendouz M., The use of non-destructive tests to estimate self-compacting concrete compressive strength. *MATEC Web of Conferences* 149 (2018) 01036. https://doi.org/10.1051/matecconf/201814901036

[51] Guendouz, M., Boukhelkhal, D., Bourdot, A., Babachikh, O., Hamadouche, A. The effect of ceramic wastes on physical and mechanical properties of eco-friendly flowable sand concrete, In: Mhadhbi, M. (ed.) Advanced Ceramic Materials, IntechOpen, 2021 1–13. https://doi.org/10.5772/intechopen.95041

[52] Hadjadj M., Guendouz M., Boukhelkhal Dj., Combined effects of ceramic and granite industrial wastes on engineering properties of self-compacting sand concrete. *Environmental Engineering and Management Journal* 24(12) (2025) 2585-2600. http://doi.org/10.30638/eemj.2025.201

[53] Bouchaour-Djabeur S., Benabdeli K., Taib N., Cork oak acorns of the Hafir-Zarieffet oak cork forest (Tlemcen, Algeria): characteristics, health status and insect infestation. *Geo-Eco-Trop* 45(4) (2021) 599-615.

[54] Amziane S., Collet F., Lawrence M., Magniont C., Picandet V., Sonebi M., Recommendation of the RILEM TC 236-BBM: characterisation testing of hemp shiv to determine the initial water content, water absorption, dry density, particle size distribution and thermal conductivity. *Matererials and Structures* 50 (2017) 1-11. https://doi.org/10.1617/s11527-017-1029-3

[55] Wu F., Liu C., Sun W., Ma Y., Zhang L., Effect of peach shell as lightweight aggregate on mechanics and creep properties of concrete. *European Journal of Environmental and Civil Engineering* 24(14) (2020) 2534-2552. https://doi.org/10.1080/19648189.2018.1515667

[56] *Sablocrete, Concrete: Characteristics and Use Practices*, Press. L'Ecole Natl. Ponts Chaussées LCPC Paris, 1994.

[57] Hamraoui S., Boukhelkhal D., Guendouz M., Abdennebi B., Fortas A., Development of a novel plant-based flowable sand concrete containing pretreated date seed as renewable aggregates. *Studies in Engineering and Exact Sciences* 6(1) (2025) e13458-e13458. https://doi.org/10.54021/seesv6n1-011

[58] *EFNARC, Guidelines for Self-Compacting Concrete*. European Federation for Specialist Construction Chemicals and Concrete Systems, Norfolk, UK, 2002.

[59] *ASTM C567/C567M-19, Standard Test Method for Determining Density of Structural Lightweight Concrete*. ASTM International, 2020.

[60] *ASTM C642-21, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*. ASTM International, 2022.

[61] *NF EN 993-15, Test methods for dense shaped refractory products - Part 15: Determination of thermal conductivity by the hot wire (parallel) method*. AFNOR, 2005.

[62] *NF EN 196-1, Methods of Testing Cement—Part 1: Determination of Strength*. AFNOR, 2016.

[63] Guermiti L., Benamara D., Guendouz M., Experimental and numerical investigation of the workability and mechanical properties of High-performance fiber- reinforced fluid concrete (HPFRFC). *International Journal of Advanced Studies in Computer Science and Engineering, IJASCSE* 11 (2022) 8-25. Available at: https://new.ijascse.org/IJASCSE- volume-11-issue-05.html

[64] Charai M., Mezrhab A., Moga L., Karkri M., Hygrothermal, mechanical and durability assessment of vegetable concrete mixes made with Alfa fibers for structural and thermal insulating applications. *Construction and Building Materials* 335 (2022) 127518. https://doi.org/10.1016/j.conbuildmat.2022.127518

[65] Guermiti L., Guendouz M, Boukhelkhal Dj., Abid S., Hadjadj M., Potential of producing lightweight cork-based mortars reinforced with polyethylene fibers for building applications. *Building* 16(1) (2026) 102. https://doi.org/10.3390/buildings16010102

[66] Fengel D., On the changes of the wood and its components within the temperature range up to 200° C – Part III Thermally and mechanically caused structural changes in sprucewood, *Holz Als Roh- Werkst.* 24 (1966) 529-536.

[67] Nakanishi E.Y. *et al.*, Hot water treatment effect in the elephant grass ashes calcinated at different temperatures. *Matéria Rio J* 23(3) (2018) e12209. https://doi.org/10.1590/S1517-707620180003.0543

[68] Yew M.K., Tan C.T., Yew M.C., Lee F.W., Beh J.H., Lee J.C., Properties of concrete with untreated and treated oil palm shell: A comprehensive review. *Journal of Building Engineering* 112 (2025) 113627. https://doi.org/10.1016/j.jobe.2025.113627

[69] Wu F., Yu Q., Brouwers H., Long-term performance of bio-based miscanthus mortar. *Construction and Building Materials* 324 (2022) 126703.

[70] Wu F., Yu Q., Brouwers H., Effects of treated miscanthus on performance of bio-based cement mortar. *Journal of Sustainable Cement-Based Materials* 12(4) (2023) 357-368. https://doi.org/10.1080/21650373.2022.2059794

[71] Hamraoui S., Guendouz M., Boukhelkhal Dj, Hadjadj M., Benrekia I., Bouldoum A.E., Reinforcing the properties of self-compacting mortar based on agro-waste fine (walnut shell) aggregates by alkaline treatment. *Studies in Engineering and Exact Sciences* 6(1) (2025) e13724-e13724. https://doi.org/10.54021/seesv6n1-022

[72] Hamraoui S., Boukhelkhal Dj., Guendouz M., Ahmedi Y., Development of a lightweight self-compacting mortar based on an agricultural by-product (walnut shells) as fine aggregates. *Studies in Engineering and Exact Sciences* 6(1) (2025) e13725-e13725. https://doi.org/10.54021/seesv6n1-023

[73] Rilem, Functional classification of lightweight concrete, *Materials and Structures* 11 (1978) 281-283. https://www.rilem.net/publication/publication/170?id_papier=5143

[74] Chen Y., Yu Q., Brouwers H., Acoustic performance and microstructural analysis of bio-based lightweight concrete containing miscanthus. *Construction and Building Materials* 157 839-851, 2017. https://doi.org/10.1016/j.conbuildmat.2017.09.161

[75] Benimam S., Bentchikou M., Debieb F., Kenai S., Guendouz M., Physical and mechanical properties of cement mortar with LLDPE

powder and PET fiber wastes. *Advances in Concrete Construction* 12(6) (2021) 461-467. https://doi.org/10.12989/acc.2021.12.6.461

[76] Guendouz M., Debieb F., Boukendakdji O., Kadri E.H., Bentchikou M., Soualhi H., Use of plastic waste in sand concrete, Journal of Materials and Environmental Science 7(2) (2016) 382-389.

[77] Rosales J., Cabrera M., Beltran M.G., Lopez M., Agrela F., Effects of treatments on biomass bottom ash applied to the manufacture of cement mortars. *Journal of Cleaner Production* 154 (2017) 424e435. http://dx.doi.org/10.1016/j.jclepro.2017.04.024