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Effect of using spent coffee grounds wastes as aggregates on physical and thermal properties of sand concrete

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ABSTRACT/RESUME

Abstract: *Coffee is one of the most popular and consumed beverages worldwide; as its consumption increases, the coffee waste increases and will become a serious environmental problem. This paper presents a feasibility study of manufacturing sand concrete by introducing recycled spent coffee grounds (SCG) as fine aggregate. The sand is substituted in its volume by SCG at percentages of 0%, 5%, 10%, 15% and 20%. The effect of SCG waste on workability, porosity and thermal properties of the sand concretes was studied. The experimental results show that the use of SCG as fine aggregate to replace partially the sand, contributes to reducing the workability of the SCG based sand concretes. However, the thermal properties are improved with the increasing rate of SCG, which could allow using SGC based concrete in various types of structural components with interesting insulating properties.*

I. Introduction

The building sector is responsible for a great part of energy consumption with increasing levels of CO_2 emissions. Approximately 40 % of the total energy consumed in the world, it's required for heating and air conditioning of buildings which represents 36 % of the global CO_2 emissions [1], and about 50 % of this energy is lost through the walls [2]. Hence, the development of new building materials with a good insulation capacity has now become an effective solution for reducing building energy demand [3]. Indeed, several researches have been developed in recent years and focus on the improvement of the thermal insulation properties of construction building materials [4-11].

At the same time, the use of alternative building materials and the recycling of landfill wastes, for an environmental sustainability, has become a priority for the construction industry today; as rapid global urbanization and associated infrastructure development increase the rate of materials consumption on construction sites, creating a shortage of conventional building materials and putting a strain on natural resources including non-renewable raw materials. As well as due to the landfill space which is becoming increasingly scarcer, the use of recycled construction material derived from industrial wastes for improving resources, and waste management, can prove to be an economical and environmental solution for urban developers and construction contractors [12-16].

Coffee is one of the foremost popular beverages and is classified as the second most important consumer product in the world [17]. As its consumption increases the spent coffee waste quantities, which represent a significant share of municipal organic wastes and the prime contributor of organic wastes in municipal landfills, with its insoluble granular nature [18]. An estimate done, suggested that as a result of coffee brewing, the world produced 7.4 million tons of SCG waste [19]. Hence, SCG is becoming a problem waste material that should be focused as a target in waste management.

The SCG waste has been investigated in recent years for potential usage in engineering applications: as agricultural fertilizer [20, 21], or as a leachate absorbent in a landfill and wastewater treatment [22, 23], as antioxidant material source [24], in biorefinery [25, 26], as source of biodiesel production and fuel pellets in industrial boilers [27, 28], as a replacement material for subgrade fills in geotechnical and nonstructural materials in road embankments [29-31], for energy recovery, bioenergy and phenolic compounds [32].

The use of spent coffee grounds in the construction field is still a relatively new concept. However, the use of this organic waste as a renewable and environmentally friendly construction material in construction areas may represent an effective response both to the problem of reducing the environmental impact and to the development of an increasingly sustainable building industry [18, 33].

Several researchers have studied the physic-mechanical and thermal properties of composites incorporating spent coffee grounds [34-45]. It is shown that the use of this waste as aggregate or fillers in concrete composite material leads to a decrease in workability, density and mechanical properties of mixtures [34-37]. Almeida et al. [37] found an increase in concrete compressive strength when replacing 5% of natural sand with coffee residue. Lachheb et al. [38] studied the influence of replacing 2, 4 and 6% of sand with SCG on the thermal properties of plaster composite. They found a reduction of the thermal conductivity value from 0.50 to 0.31 W/m.K by the replacement of 6% of sand with SCG. It observed also a reduction of about 20% in the building cooling and heating loads when conventional material substituted by the proposed one. As well as, a reduction to 1500 kg CO_2 was estimated annually for the studied case when utilizing SCG.

Fonseca et al. [39] reported that the use of 0, 5, 10, 15, and 20% of SCG as an additive in ceramic manufacturing decreases the value of density and mechanical strength of mixtures. Nevertheless, an excellent improvement in thermal insulating properties was obtained, with a reduction of 30 and 70% in thermal conductivity value were observed by adding 5 and 20% of SCG in mixture, respectively. Jaddu et al. [41] observed also a decrease in weighing and compressive strength of ceramic bricks with increasing the amount of spent coffee grounds. A reduction of about 50% in the thermal conductivity of bricks was observed by Velasco et al. [42] when adding 17% of coffee grounds. An improvement in mechanical, physical and thermal properties has also been shown by Eliche-Quesada et al. [44] for bricks consisting of 3 to 5% coffee grounds as organic residue with raw clay.

Recently, studies have been done by some researchers to assess the possibility of using spent coffee residues as cement in concrete for its pozzolanic possessions. Lin et al. [46] investigated the replacement of 2, 3, 5, 10 and 15% of cement by coffee residues in mortar. The authors found a decrease in compressive strength for more replacement ratio and reusing up to 10% of coffee residue can get valuable efficiencies whether in the economic or environmental aspect. Similarly, Demissew et al. [34] studied the effect of replacing 0, 2, 3, 5, 10, and 15% of the ordinary Portland cement (OPC) with coffee residues in the production of conventional concrete. They show that, the replacement of up to 10% of OPC by coffee residues achieved advanced compressive strength and density. Charai et al. [47] recycled SCGs as cement to prepare bio-based mortars with different SCGs weight concentrations ranging from 0 to 40 wt%. They found a decrease of about 70.8% in the mortar's thermal conductivity and 45.7% in the thermal diffusivity, by replacing 30wt% of cement by SCGs.

Sand concrete is fine concrete, which usually consists of a mixture of sand, cement, fillers, admixtures, and water. It is to be differentiated from ordinary concrete by its high dosage of sand and from mortar by its low cement content [48, 49]. Nowadays, Algeria knows a considerably increased demand for aggregates related to the country development in building matter, especially in the south of the country's where there's a deficit in aggregates, and the dune sand is abundant there. For these areas, the use of sand concretes in the building or road construction industry can provide an attractive alternative solution for various applications. Moreover, this latter has comparable strength and rather modest performances than ordinary concrete [50].

Different mineral and organic wastes were added to sand concrete in previous works [51-55]. However, the addition of SCG to this type of concrete has not been studied before. In addition, the average quantity of daily coffee waste produced by 1473 Cafeterias in Medea city is estimated at 11784 kg/day. In this context, the present work aims to study the feasibility of recycling SCG in sand concrete without any transformation except received, to minimize the cost of the final material. The effect of partial substitution of sand by SCG on the physical and thermal properties of the obtained composite material has been studied and analyzed.

II. Materials and methods

II.1. Materials

Two different types of sand were employed in this study. The first one is dune sand (DS) extracted from south Algeria (near he Djelfa region), with a maximum grain diameter of about 2 mm and containg 5% of grain less than 0.08 mm. The second one is a crushed sand (CS) extracted from the El Hachimiya region (around the city of Bouira). It presents a continuous particle size

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distribution ranging from 0.08 to 5 mm. Fig. 1 shows the particle size distributions of the two sands used, and Table 1 lists the set of their physical characteristics.

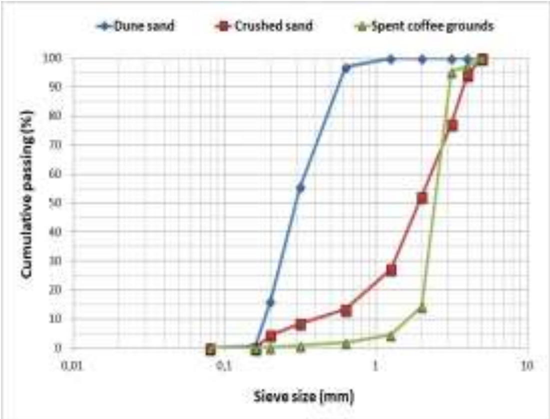

Figure 1. *Particle size distribution of dune sand (DS), crushed sand (CS), and spent coffee grounds (SCG).*

The X-ray Diffraction analysis and SEM investigation demonstrate the essentially siliceous nature and rounded grains shape of dune sand (Fig. 2-a). Contrary to the crushed sand which has limestone nature and angular grains shape (Fig. 2-b). The difference between these two sands lies, therefore, in their nature, form and particle size distribution.

Table 1. *Physical properties of sands and SCG.*

Property	*DS*	*CS*	*SCG*
Bulk density (kg/m^3)	*1400*	*1420*	*387*
Specificdensity (kg/m^3)	*2500*	*2580*	*800*
Water absorption (%)	*2.50*	*1.20*	*3.25*
Sand equivalent	*75.00*	*48.00*	*/*
Fineness modulus	*1.16*	*3.18*	*2.9*
Compactness (%)	*55.00*	*56.00*	*48.00*
Porosity (%)	*45.00*	*44.00*	*52.00*

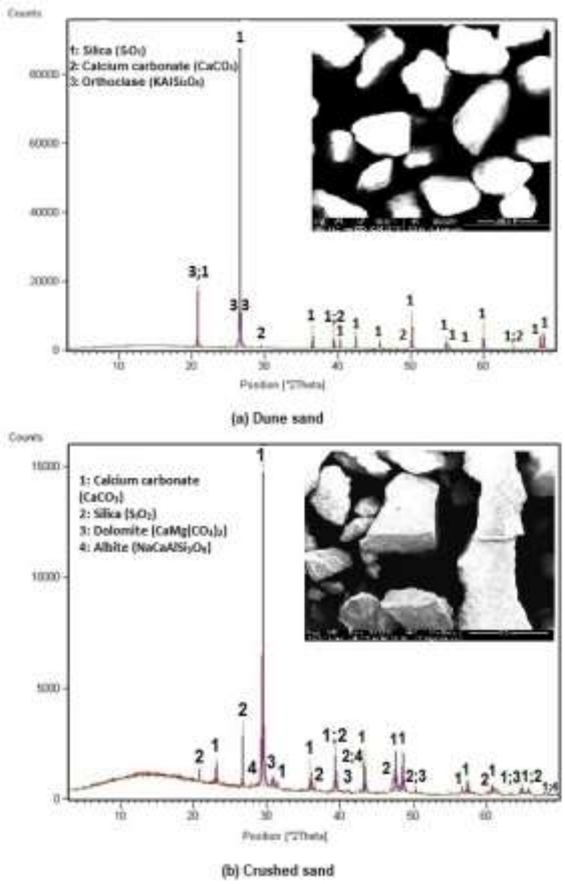

Figure 2. *Particle size XRD analysis and SEM images of grain form of the dune sand (2/a) and crushed sand (2/b).*

A Portland cement CPJ-CEMII/A 42.5 N from MASCARA Factory in Algeria was used throughout this study; with a density of 3.10 g/cm^3 and specific surface area of 3500 cm^2/g. The filler used in this work is a limestone powder, with a specific density of 2.66 g/cm^3 and specific surface area of 2420 cm^2/g.

The spent coffee grounds (SCG) obtained from a local coffee shop (Arabica type), it consists of fine brown particles with a maximum size grain of 4 mm and, similar to natural sand which is the main component used in sand concrete (Fig. 1 and Fig. 3). SCG wastes were dried for 24h at 105°C and then stored in airtight bags to prevent its decomposition during prolonged storage for subsequent experiments. The physical properties and chemical analysis of SCG are presented in Table 1 and Table 2, respectively. The SEM investigation of SCG reveals the angular shape of their grains (Fig. 3).

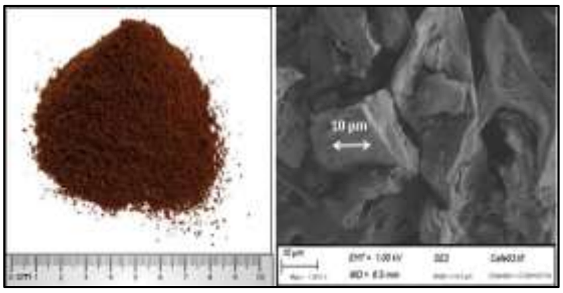

Figure 3. *General aspect and SEM micrograph of spent coffee grounds (SCG).*

Table 2. *Chemical analysis of SCG used.*

Element	*Quantity (%)*
Carbon (C)	*48.70*
Hydrogen (H)	*s.d*
Azotes (A)	*3.3*

To obtain a malleable sand concrete, a modified poly carboxylates based plasticizer "MEDAFLUID 104" produced by GRANITEX group (Algeria), with a solid content of 35%, was used as a chemical admixture for all mixes in this study. The used mixing water in this work is obtained from the distribution drinking water.

II.2. Mix design

In this study, the sand concrete formulation is based on the theoretical method of Sablocrete project [56]. Two families of sand concrete, based on dune sand (DS) and crushed sand (CS), and with or without SCG are studied. The mixtures are named as follows and the percentages of SCG used were identified in a precise way.

- **CDSC:** Control dune sand concrete (without SCG).
- **DSC SCG:** Dune sand concrete with spent coffee grounds.
- **CCSC:** Control crushed sand concrete (without SCG).
- **CSC SCG:** Crushed sand concretes with spent coffee grounds.

Ten (10) sand concrete mixes were manufactured with constant cement and filler content of 350 kg/m^3 and 200 kg/m^3, respectively. The water/binder ratio was kept also constant to 0.55. The SCG grains were introduced by partial replacement of natural sand at different percentages of weight: 5, 10, 15 and 20%. The mix proportions of all SC mixes are given in Table 3 and Table 4.

Table 3. *Mix proportion of DSC with SCG.*

Constituents	*CDSC*	*DSC SCG (%)*			
		5	*10*	*15*	*20*
Sand (kg/m^3)	*1320*	*125*	*1188*	*112*	*105*
Cement (kg/m^3)	*350*	*350*	*350*	*350*	*350*
Fillers (kg/m^3)	*200*	*200*	*200*	*200*	*200*
Water (l/m^3)	*302*	*302*	*302*	*302*	*302*
*P (%)**	*1*	*1.30*	*1.35*	*1.65*	*2*
SCG (kg/m^3)	*0*	*19.3*	*38.6*	*58.*	*77.3*

*The admixture percentage is calculated, in mass, compared to the cement mass.

Table 4. *Mix proportion of CSC with SCG.*

Constituents	*CCSC*	*CSC SCG (%)*			
		5	*10*	*15*	*20*
Sand (kg/m^3)	*1560*	*1537*	*151*	*1491*	*1469*
Cement (kg/m^3)	*350*	*350*	*350*	*350*	*350*
Fillers (kg/m^3)	*200*	*200*	*200*	*200*	*200*
Water (l/m^3)	*302.5*	*302*	*302*	*302.5*	*302.5*
*P (%)**	*1*	*1.25*	*1.5*	*1.90*	*2*
SCG (kg/m^3)	*0*	*22.69*	*45.*	*68.07*	*90.76*

*The admixture percentage is calculated, in mass, compared to the cement mass.

II.3. Test procedures

A total of 60 simples with different dimensions were prepared for each mixture to determine the porosity and thermal conductivity of the mixes at 28 days.

The porosity of hardened sand concretes is evaluated on three (4×4×16) cm^3 samples for each mixture at 28 days, on the base of total water immersion test of prepared samples under vacuum in accordance with NF P18-459 standard [57].

The thermal properties were carried out by the hot wire technique on three 10×10×4 cm^3 simples for each mixture using the CT-meter device equipped with a long hot wire (Fig. 4) and according to NF EN 993-15 standard [58]. The main assumption of this method is to consider a cylindrical geometry with a radial transfer and an infinite length of the hot wire. As well as, the studied material that constitutes an infinite surrounding is supposed to be homogeneous and isotropic.

The measurement of thermal properties is based on the analysis of the temperature rise versus logarithmic heating time. For this test, the simples were treated using a sandpaper sander to obtain smooth, flat and parallel surfaces. After, well, they were oven-dried at 60°C until weight stabilization to remove any moisture. For all specimens, the measurements should be taken several times to

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ensure the representativeness of the thermal characteristics value. These measurements are: thermal conductivity (λ), thermal diffusivity (a) and specific heat (Cp).
The thermal conductivity represents the quantity of heat transferred per unit area and per unit of time under a temperature gradient. Where, the thermal diffusivity characterizes the concept of the thermal inertia. It is well known that the relationship between the thermal conductivity and the specific heat can lead to the determination of the thermal diffusivity.

$$Ca = \lambda/\rho \times Cp \ (m^2/s) \quad (1)$$

With
ρ: is the material density.

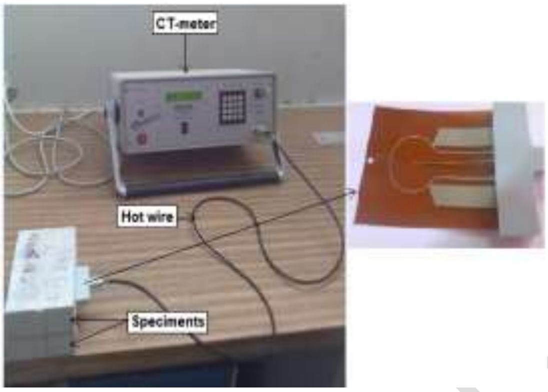

Figure 4. *Hot wire apparatus.*

III. Results and discussion

III.1. Porosity

In Table 5 are given the porosity results of different sand concrete mixes after 28 days of water maturation of samples.

The results presented in table 5 clearly show that whatever the nature of sand employed, the porosity of all sand concrete mixes increases with the increase of SCG content. In addition, the porosity is 6.3 and 6 times greater for DSC20SCG and CSC20SCG compared to CDSC and CCSC, respectively. This increase in porosity values is probably due to the morphological structure of spent coffee ground aggregates (Fig. 3) and their high water absorption (Tab. 1) compared to natural sand, which causes an increasing microstructure porosity of concrete, as well as to the poor adhesion between the spent coffee grounds grains surface and binder paste. As reported by Lo et al. [60], including high water absorption aggregate affects the microstructure of concrete by increasing the porosity of the interfacial zone of the paste. This increase in porosity by adding SCG in the sand concrete is quite comparable to the observations found by the authors in [42, 44, 48] for other type of concrete.

Table 5. *Porosity, thermal conductivity and diffusivity of hardened SC mixes (28 day).*

Concrete	*Porosity (%)*	*Thermal conductivity (W/(m.K))*	*Thermal diffusivity (m^2/s)*
CDSC	*4.00*	*1.252*	*1.64*
DSC5SCG	*8.90*	*1.188*	*1.61*
DSC10SCG	*14.60*	*1.047*	*1.30*
DSC15SCG	*19.81*	*0.752*	*0.72*
DSC20SCG	*25.20*	*0.704*	*0.64*
CCSC	*3.60*	*1.486*	*2.00*
CSC5SCG	*8.40*	*1.236*	*1.64*
CSC10SCG	*13.89*	*1.102*	*1.32*
CSC15SCG	*18.79*	*0.850*	*0.95*
CSC20SCG	*24.10*	*0.778*	*0.82*

III.2. Thermal conductivity

The thermal conductivities measured at 28 days of storage are shown in Table 5. It is known that materials with low thermal conductivity present a good thermal insulating ability. As seen from this table, the thermal conductivity of control sand concretes was 1.25 W/m.K and 1.48 W/m.K for DSC and CSC, respectively. These values decrease to 0.70 W/(m.K) for dune sand concrete and 0.78 W/(m.K) for crushed sand concrete when 20% of normal sand was replaced by SCG. A linear variation in thermal conductivity is observed with the rate of spent coffee grounds addition, which is in accordance with the results observed by several authors in composite systems [4, 41-43, 45, 48]. This decrease in thermal conductivity of mixes is probably caused by the lower thermal conductivity coefficient of the SCG aggregate (0.20 W/m.K) compared to natural aggregate (2.00 W/m.K).

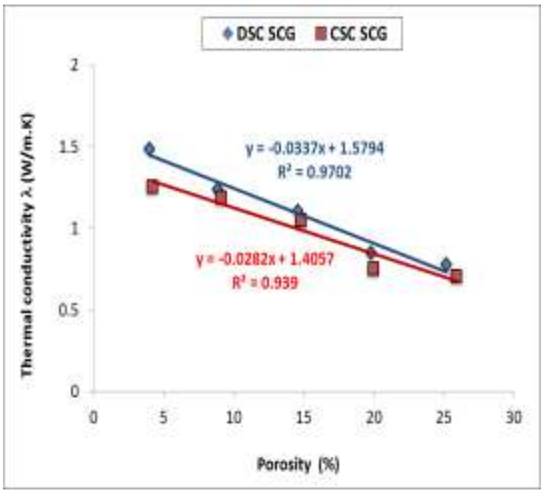

Figure 5. *Relation sheep between thermal conductivity and porosity of SC containing spent coffee grounds.*

As shown in Fig. 5, there is a strong relationship between the thermal conductivity and porosity of all sand concretes (R^2 = 0.97 for DSC and 0.94 for CSC).
Therefore, this reduction in thermal properties becomes also from the porosity increase induced by the SCG (Table 5). Indeed, the air containing in the pores has a much lower thermal conductivity (0.024 W/m.K) than that of all other sand concrete components. As demonstrated by Korjenic et al. [60], incorporating organic waste into the cement matrix modifies its microstructure and improves the thermal insulation capacity of building structures.
When analyzing the effect of sand nature on sand concrete thermal conductivity, Table 5 shows that the sand concrete with dune sand, which is the finest sand (higher porosity), has lower thermal conductivity than that of crushed sand concrete, which contains the coarsest sand. It is observed also that this difference tends to disappear with the increase of SCG content.

III.3. Thermal diffusivity

Thermal diffusivity expresses the ability of a body to transmit heat rather than absorb it. Consequently, the lower the thermal diffusivity of a material, the longer it takes for heat to pass through it.
The Thermal diffusivity results obtained at 28 days of age for SC mixes with and without SCG are shown in Table 5. These results show that with the replacement of natural sand by 20%wt SCG, the thermal diffusivity decreases from 1.64 m^2/s to 0.64 m^2/s for DSC and from 2 m^2/s to 0.82 m^2/s for CSC. This decrease is probably due to the heterogeneity in morphological properties of this composite material and agrees with that found by Lachheb [38] for Plaster with coffee grounds wastes as aggregate.

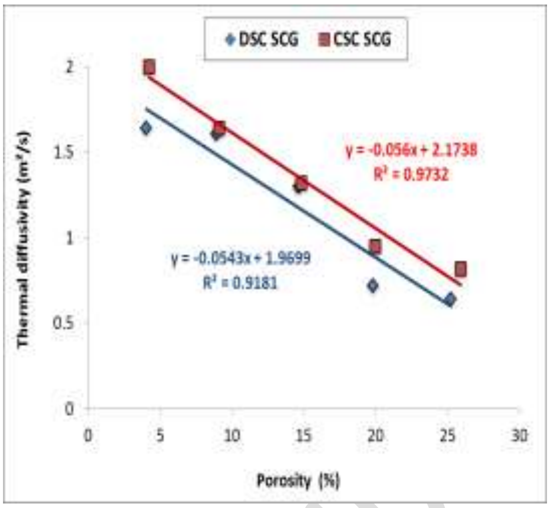

Figure 6. *Relation sheep between thermal diffusivity and porosity of SC containing spent coffee grounds.*

A good relationship was observed also between the thermal diffusivity and porosity, as well as, thermal diffusivity and thermal conductivity of all SC mixes, with a linear correlation as shown in Fig. 6 (R^2 = 0.92 for DSC and 0.97 for CSC) and Fig. 7 (R^2 = 0.91 for DSC and 0.94 for CSC) respectively.

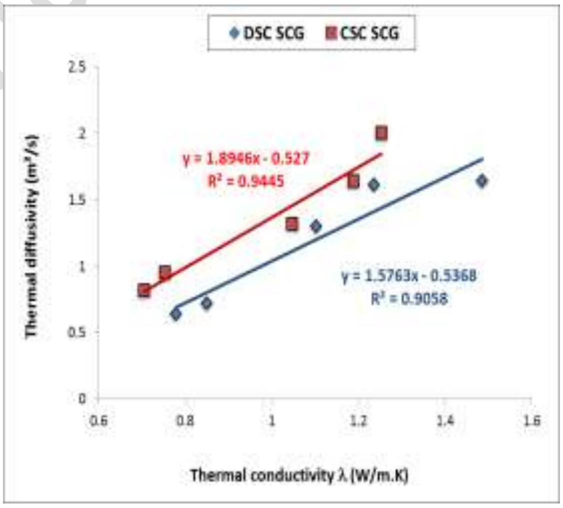

Figure 7. *Relation sheep between thermal diffusivity and thermal conductivity of SC containing spent coffee grounds.*

As investigated in this study, recycling SCG can be an ecological and economic alternative for producing highly technological material. Such as lightweight aggregate which is associated with greater environmental advantages, due to their lightness (e.g. reduction in the consumption of fuel during transport) and high porosity (e.g. increase of thermal insulation in buildings), which are also essential in terms of cleaner production. Furthermore, the incorporation of SCG wastes in concrete, exhibit good technological properties with

similar or better performances than other insulating materials, such as polystyrene concrete, shaving wood concrete, plastic waste concrete, etc. Where, a higher compressive strength was obtained in our sand concretes (SCSCG) compared to that contains wood shavings studied by Bederina et al. [52] for the same thermal conductivity value (0.70 W/m.K). As well as, lower thermal conductivity and density with the same compressive strength, are observed for our sand concretes compared to those observed respectively by Belhadj et al. [54] and Guendouz et al. [61], for sand concrete with barley straws and plastic waste.
Given the thermal conductivity values obtained for our sand concretes, DSC20SCG and CSC20SCG with λ < 0.80 W/(m.K) (Table 5), these spend coffee ground based sand concrete could indeed be used as an insulating material [62]. In addition, and in term of cost, the use of SCG waste in concrete requires no additional cost for the production of lightweight concrete compared to other insulating materials. In this respect, the use of this waste (SCG) is less expensive and it is strongly recommended to be used as fine aggregate in composite concrete.
Since the SCG is vegetal waste, we have found that it is necessary to study the long term durability behavior of the studied SCG based concretes (work in progress) such as sorptivity, creep and shrinkage, bond strength and corrosion. These properties are not considered in our study, so more research is needed in this area for future works.

IV. Conclusion

This paper has presented the recycling, and the use of spent coffee ground waste as aggregate in dune and crushed sand concrete. The results can be summarized and the conclusions are:

- The use of spent coffee grounds as partial replacement of dune or crushed sand contributes to increase the porosity of sand concrete. The DSC20SCG and CSC20SCG mixtures have the highest porosity values, which are 6.3 and 6 times greater for compared to CDSC and CCSC, respectively.
- The replacement of natural sand with the SCG in sand concrete improves the thermal conductivity and reduces the heat diffusion of the mixtures. The thermal conductivity decreases from 1.25 W/m.K and 1.48 W/m.K for control DSC and CSC, respectively, to 0.70 W/m.K and 0.78 W/m.K for dune sand concrete and crushed sand concrete when 20% of normal sand is replaced by SCG.
- The thermal conductivity of dune sand concrete was better (lower value) than that of crushed sand concrete. However, this difference in thermal conductivity decreased with the increase on spent coffee ground aggregates contents.
- The Thermal diffusivity decreases from 1.64 m^2/s to 0.64 m^2/s for DSC and from 2 m^2/s to 0.82 m^2/s for CSC sand concrete when 20% of normal sand is replaced by SCG.
- A linear regression in thermal conductivity and diffusivity was found with the increase rate of spent coffee grounds addition,
- The sand concretes containing 15% and 20% of SCG are regarded as insulating materials, as their thermal conductivity is less than 0.70 W/m.K.
- The obtained thermal properties results show that it is possible to use the coffee grounds as a suitable alternative material instead of the insulating building materials. Thereafter, the use of these new types of concretes is recommended in construction for many non-structural elements, prefabricated panels, separation in buildings, facades, bottom ceilings, bathrooms, etc.

Finally, this study insures that the reusing up to 10% of coffee waste in sand concrete is an appropriate solution to the problem of natural pollution, resource conservation and energy savings for future generations. It leads to reduce the response of materials, solve some environmental problems, and improving thermal insulation.

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