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Physical and thermal properties of lightweight self-compacting mortar made with recycled walnut shells as fine agreggrates

Dj. Boukhelkhal*, M. Guendouz, Z. Triki

LME Laboratory, University of Medea, Algeria.
LBMPT Laboratory, University of Medea, Algeria.

*Corresponding author: boukelkal_djamila@yahoo.fr ; Tel.: +213 778164144

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ABSTRACT/RESUME

Abstract: *The aim of this work is to investigate the possibility of recycling Walnut Shell wastes (WS) as fine aggregates in lightweight self-compacting mortar (SCM). In the experimental procedure, the natural sand was partially replaced by the WS waste at various replacement ratios (0; 10; 20; 30 and 40%). The thermal conductivity and some physic-mechanical properties of the SCM containing WS were studied and compared with control SCM (CSCM). The test results showed that, depending on the amount of WS aggregate, unit weight and thermal conductivity of concrete were reduced and the capillary water absorption was increased with the use of WS aggregates and for all the lightweight SCMs considered. Moreover, reductions in mechanical properties of concretes have been obtained with decreasing concrete unit weights. In addition, substitution ratio of 30% was found to be the optimum volume ratio of WS for getting lightweight structural SCM with appropriate fresh and hardened properties.*

I. Introduction

The production of new concretes, which will simultaneously meet the requirements of modern civil engineering structures as workable materials and structure mass reduction such as self-compacting concrete (SCC) and lightweight concrete (LWC) materials is one of most technological development in the modern construction industries. LWC is one of the best solutions to the problem of reducing the dead load of the structure [1, 2], unlike the SCC; it has a low viscosity and large rate of flow which is very important for concrete pumping, particularly in multistory buildings [3, 4]. In order to achieve combined benefit from both types of concrete; many attempts are made for successfully integrating them into one type as lightweight self-compacting concrete (LWSCC) [5-11].
On the other hand, the major factors affecting the heat transfer in buildings, is the thermal conductivity of the materials used. Thus, for reducing the energy usage and heat loss in construction, the construction materials with low thermal conductivity should be preferred [12-14]. Hence, the variation in the materials used in building construction greatly affects the properties of these concretes. In addition, replacing natural aggregate in concrete construction with waste materials, can lead to discovering ecological building materials [15-17].
Lightweight construction concretes are generally produced with lightweight aggregate (LWA) which can either of natural sources or artificially constructed from by-products processing through some industrial processes [18-23]. Walnut shell wastes (WS) are one of the available agricultural wastes which present in large quantities in landfill and that can be used as alternative aggregate in concrete [24-26]. Since, it is a new material; not much work available in the literature has highlighted its effects on fresh and hardened properties of SCC.

Hilal et al. [5] used WS as a replacement of coarse aggregate for constructing SCC by employing ten different volume fractions from 5% to 50% with each increment of 5%. They show that the increase of WS volume fraction decreased the workability and mechanical strengths of SCC mixes. However; the lightweight self- compacting concrete (LWSCC) can get at fraction volume of WS equal and or more than 35%. Where, slump flow diameter (SFD), compressive and bond strengths were 560 mm, 35 MPa and 6.55 MPa respectively.
Cheng et al. [27] studied the effect of replacing normal coarse aggregate by walnut shells (WS) in the production of lightweight wet-mix shotcrete (LWMS). They found a reduction in slump, pressure drop, compressive and splitting tensile strengths with increasing the amount of WS. Kamal et al. [28] found that not any significant effect on compressive strength of concrete by using up to 30% of walnut shells as an alternative to fine aggregate with water/cement ratio of 0.38. Moreover, the results indicated the possibility of using walnut shells in the manufacturing of concrete due to many advantages and most of which are environmentally friendly and viable structurally.
Husain and Ahmad [29] studied the possibility of using walnut shell powder (WSP) as fine aggregate at three different contents as 10, 20 and 30% in concrete production. They observed a significant decrease in compressive strength by increasing the quantity of WSP. The optimum results were found for concrete with 20% of WSP content.
In order to achieve concrete characteristics that will simultaneously meet the requirements of modern civil engineering structures, environmental protection and sustainable development, this work aim to study the feasibility of using walnut shells waste as fine aggregate (sand) in the manufacturing of self-compacting mortar (SCM). For this study, the volume of sand in SCM was substituted by WS waste with a fraction of 10%, 20%, 30% and 40%. The physic-mechanical properties and thermal conductivity of the obtained walnut shells waste based SCM are studied, analyzed, and compared to those for the control SCM.

II. Materials and methods

II.1. Materials

Limestone based Composite Portland Cement CEM II/A 42.5 with a fineness of 3370 cm2/g and a specific gravity of 3.15 g/cm3 was used in this study. Its average compressive strength at 28 days is 46.5 MPa.
Local natural sand extracted from the south of Algeria (quarry of Oued Souf) was used in this study (Fig. 1/a). In Table 1 are presented the physical properties of this sand. The vegetable waste employed in this study, is a walnut shell waste with brown color (Fig. 1/b). It was steamed at 105 °C for 24 hours and crushed to obtain a granulated material of diameter close to those of natural sand, with 5 mm maximum size. The physical properties of WS waste are presented in Table 1. Figure 2 shows the particle size distributions of the natural sand and walnut shell waste used.
A polycarboxylate superplasticizer type MEDAFLOW 30 was used as admixture in this study to make the self-compacting mortar character. It has a specific density of 1.07 g/cm3 and a solid content of 30%. Its recommended range of used is fixed in the data sheet between 0.3 to 2% of the cement weight. The drinking distribution water was used as mixing water in this study.

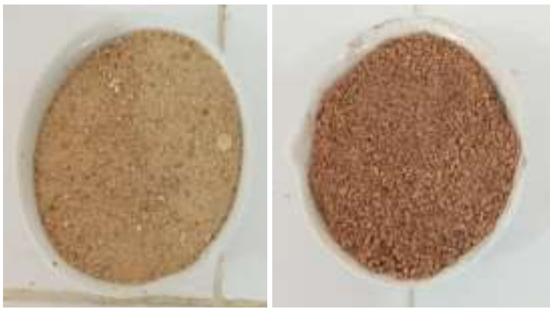

Figure 1. *Aggregates used (a/ natural sand; b/ walnut shell).*

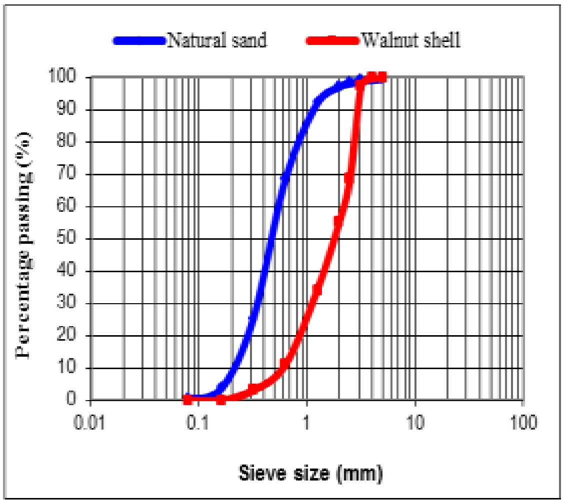

Figure 2. *Particle size distribution of natural sand and walnut shell waste.*

Table 1. *Physical properties of natural sand and WS*

Property	*NS*	*WS*
Specific density (kg/m^3)	*2670*	*1290*
Water absorption (%)	*0.42*	*2.61*
Fineness modulus	*2.25*	*3.33*

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II.2. Mix design

The mix design used in this study for determining the quantities of the different components of SCM mixtures as: cement, sand, walnut sell, water and superplasticizer, was based on the Japanese method proposed by Okamura and Ozawai [4]. The sand to mortar ratio (S/M) and the water to cement ratio (W/C) were fixed in this study at 0.5 and 0.43, respectively. The quantities of superplasticizer for all mixtures were adjusted to obtain good properties of fresh SCM mixtures with the requirements of local materials. The different SCMs mix proportions are presented in Table 2.
Five (05) SCM mixes are prepared in this study, one without any walnut shell waste and with 100% natural sand named CSCM and four (04) other mixes were prepared by replacing the natural sand by the walnut shell waste with different content (10; 20; 30 and 40 %).

Table 4. *Mix proportion of SCM mixes with WS*

Constituent	*CSCM*	*SCMWS*			
		10%	*20%*	*30%*	*40%*
Cement (kg/m^3)	*678*	*678*	*678*	*678*	*678*
Sand (kg/m^3)	*1316*	*1184*	*1052*	*921*	*789*
WS (kg/m^3)	*0*	*65*	*130*	*196*	*261*
Water (l/m^3)	*292*	*292*	*292*	*292*	*292*
Sp (kg/m^3)	*5.4*	*6.8*	*8.2*	*10.2*	*12.2*

Sp: superplasticizer.

II.3. Test procedures

The fluidity of different SCMs was measured by using mini-slump flow diameter and VFunnel flow time, according to "EFNARC [30] (Fig. 3). The dry density was evaluated according to NF EN 12390-7. The compressive strength was measured on three 40×40×160 mm samples according to NF EN 196-1. For the measurements of thermal properties, the thermal conductivity (λ) was determined on three (10×10×4) cm3 samples at 28 days of age using a CT-Meter machine according to NF EN 993-15 standard.
The water absorption by capillarity was measured according to NF EN 13057 standard at the age of 28 days on half-beam 4×4×16 cm3 specimens in contact with 5 mm sheet of water (Fig. 4).

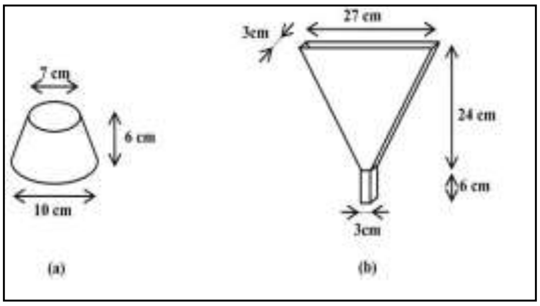

Figure 3. *Workability tests for fresh SCM mixes (a/ Mini-slump flow test; b/ V-funnel test)..*

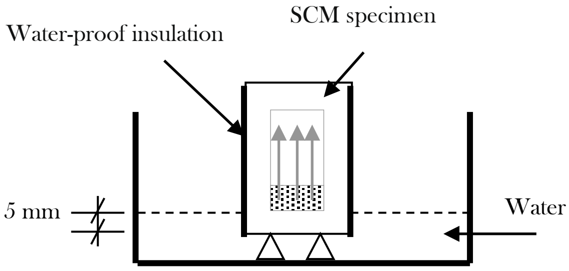

Figure 4. *Capillary water absorption test for hardened SCM..*

All the SCM specimens were produced in the laboratory environment with 20 °C and 50% RH. After 24 h of maturation, they were demolded from their molds, and placed in water at 20 °C until the days of testing.

III. Results and discussion

III.1. Characterization of SCM in fresh state

The workability of mixtures was kept constant for all SCMs (with and without WS waste) in order to be able to compare their different properties in the hardened state. For this, for all SCMs with and without WS waste, the superplasticizer quantities were adjusted to keep constant the flow diameter and flow time of mixture.
The effect of WS waste content on the superplasticizer need of the different SCM mixes to achieve a constant fluidity is shown in figure 5. It can be seen from this figure that the use of walnut shell waste increases the need on superplasticizer of mixes. An increase of about 125 % in the need of superplasticizer for SCM with 40% of WS compared to CSCM without WS. This decrease in SCM workability is maybe due to the angular shape, rough surface texture and higher water absorption of walnut shell waste grains compared to

natural sand (Table 1) and agrees with the results observed by Naji Hilal et al. [5] and Cheng et al. [27].

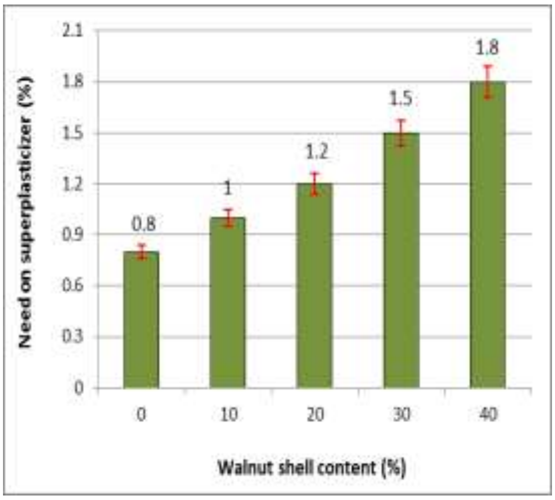

Figure 5. *Effect of walnut shell content on the need on superplasticizer of SCM mixes.*

III.2. Characterization of SCM in hardened state

III.2.1 Dry density

The effect of walnut shell waste content on dry density of SCMs is presented in figure 6.

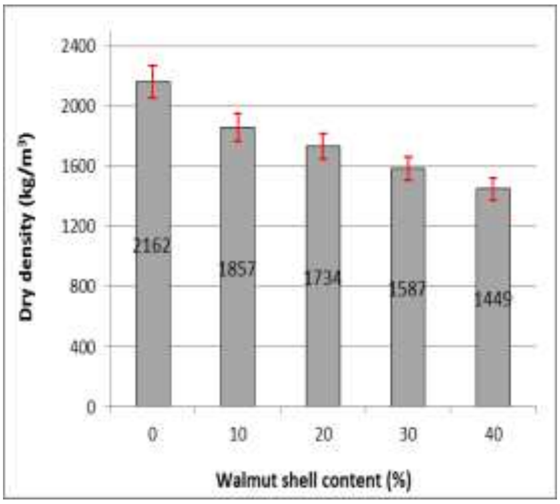

Figure 6. *Effect of walnut shell content on dray density of SCM mixes.*

The results of this figure show that the substitution of sand by the walnut shell waste causes a decrease in dry density of SCM mixes, which is surely due to the lower density of the walnut shell waste compared to natural sand (Table 1), and increasing porosity induced by the angular shape of WS grains. The highest dry density value was 2162 kg/m^3 for CSCM sample, while the lowest was 1449 kg/m^3 for SCM with 40 wt. % of walnut shell/aggregate with a decrease of about 33% in dry density.

Similar findings were reported by Kamal et al. [28] and Shahab et al. [29], for partial replacement of fine aggregates with walnut shell, Nwofor and Sule [31] for cement replacement with groundnut shell ash. And Venkatesan et al. [26] for partial replacement of coarse aggregate by walnut shell in concrete. These results were also in agreement with some results found for other agro waste concrete such as oil palm shell aggregates concrete [17], SCM with recycled olive core wastes as fine aggregates [32], cement mortar with partially replacement sand by pistachio shells waste [33], dune sand concrete containing cofee waste [34], lightweight sand concrete with wood shavings [35], and

It can be seen also from figure 6 that all SCM with WS waste can be classified as lightweight aggregate concrete (LWAC) as there dry densities are less than 2000 kg/m^3 [36]. Naji Hilal et al. [5] found the same results and they obtained lightweight SCC for mixes with more than 35% of WS contain.

III.2.2 Compressive strength

Figure 7 presents the results of 7 and 28 days of age compressive strength for SCM mixes.

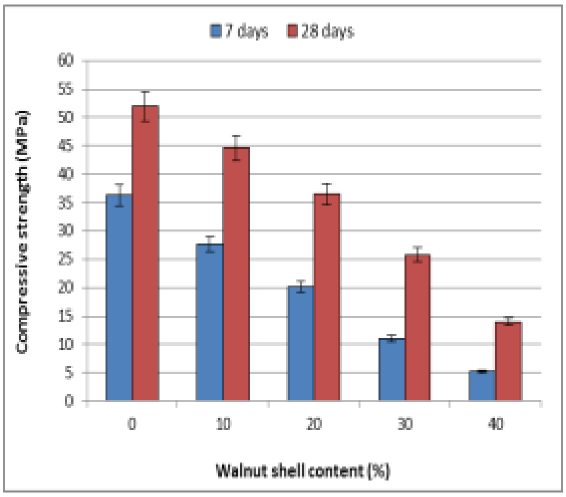

Figure 7. *Effect of walnut shell content on compressive strength of SCM mixes.*

It is clearly shown from this figure that the incorporation of walnut shell waste as aggregates decreases the compressive strength of all SCMs at early and later ages compared to CSCM. Where, the values of compressive strength at 28 days, reduced from 52 MPa for reference SCM to 26 MPa for mixture with 30% of WS, and to 14 MPa for mixture with 40% of WS. A decrease of about 86% and 73% in compressive strenth was observed for SCM with 40% of WS compared to CSCM at 7 and 28 days, respectevely.

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According to Naji Hilal et al. [5], this reduction in compressive strength is attributed to the weaker bind between WS waste grains and the cement paste surrounding them. Also, it may be due to the lack of the amount of cement paste within the concave sides of WS particles. The same results were reported by Cheng et al. [25], Venkatesan et al. [26], Kamal et al. [28] and Husain and Ahmad [29], who found that compressive strength decreases with increasing walnut shell waste content.

III.2.3 Thermal conductivity

The results of thermal conductivity as function of walnut shell waste content for the various mixture specimens, measured after 28 days of maturation, are summarized in figure 8. The findings obtained show that the thermal conductivities of all the walnut shell mixes are less than that of the control one (CSCM). The rate of the decrease is in order of 21, 36, 47 and 60% for the mixtures contained 10, 20, 30 and 40% of walnut shell waste relative to the control mortar, respectively.

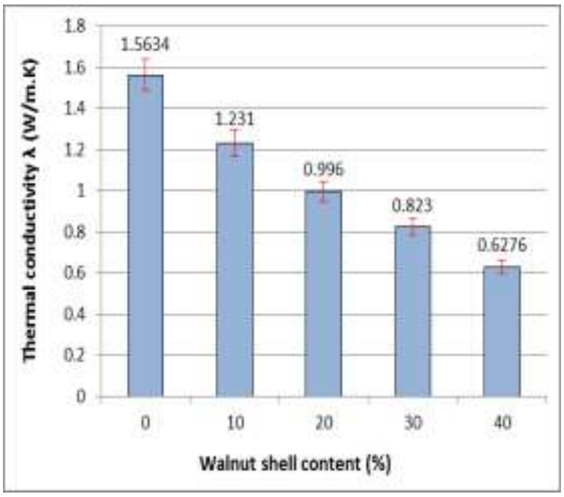

Figure 8. *Effect of walnut shell content on thermal conductivity of SCM mixes.*

This decrease in thermal conductivity is probably due to the increase in porosity induced by the walnut shell in the bond zone between the cement paste and the WS grains. In fact the air containing in this porosity has a much lower thermal conductivity than that for all the other components of the SCM (0.024 W/m.K). These results agree with those obtained by Boukhelkhal et al. [32], Sutcu et al. [37], Guendouz and Boukhelkhal [34], and Belhadj et al. [35, 38], who found an increase in the thermal insulation capacity for mixtures incorporated vegetable wastes as coffee waste, olive core waste and wood shavings.

As shown in Figure 9, there is a strong relationship between the thermal conductivity and dry density of all SCM (R^2 = 0.993). Therefore, this reduction in thermal properties becomes also from the porosity increase induced by the WS . As demonstrated by Korjenic et al. [39], incorporating organic waste into the cement matrix modifies its microstructure and improves the thermal insulation capacity of building structures.
According to the obtained results, we can say that self-compacting mortar with 20, 30 and 40% of walnut shell waste have thermal conductivities (λ) less than 1 (W/m.K) and cane be considered as more insulating compared to conventional concrete (1.5 W/m.K) [40].

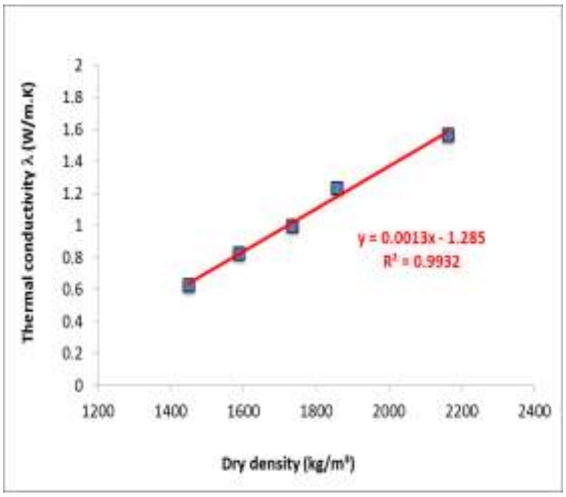

Figure 9. *Relation sheep between thermal conductivity and dry density of SCM containing walnut shell.*

III.2.4 Capillary water absorption

Capillary water absorption is an essential indicator of concrete durability. It is primarily related to the porosity of the concrete and reflects the ability of the concrete to be penetrated by water and others chemical substances.
The 28 days capillary water absorption results for mixtures as function of walnut shell waste content are presented in figure 10.

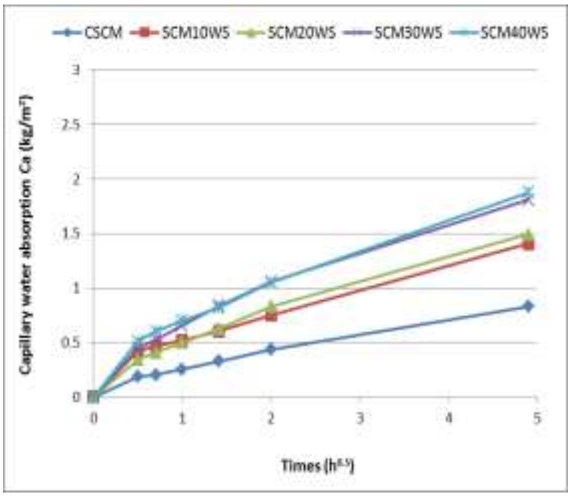

Figure 10. *Effect of walnut shell content on capillary water absorption of SCM mixes.*

It is clearly shows from these results that the water absorption values of all SCM mixtures incorporating walnut shell wastes is higher than that of control mortar CSCM. However, all SCM mixtures exhibit water absorption less than 10%. And therefore, can be classified with good quality as indicated by Neville & Brooks [36].

This increase in mixtures absorption may be due to the high level of walnut shell aggregates absorption compared to natural sand (Table 1) and agree with the results obtained by Boukhelkhal et al. [32], Barreca, et al. [41], Aslam et al. [42] and Ealias et al. [43], who found high water absorption of concrete containing olive waste, palm shell and coconut shell aggregates compared to that made with natural aggregate. In contrary, the study of Kamal et al. [28] showed inverse results. They that with increasing walnut shell content, the rate of water absorption decreased, and the optimum decrease in % absorption was observed for mixes of W/C ratio = 0.45, and walnut shells = 30% as fine aggregate. According to Jannat et al. [25] this increase on water absorption of the mixture is due to the hygroscopic nature of the walnut shell waste particles.

IV. Conclusion

This paper aimed to study the possibility of recycling Walnut Shell wastes (WS) as fine aggregates in lightweight self-compacting mortar (SCM). The main conclusions that can be drawn from the results obtained in this investigation are summarized as follows:

- A reduction in the fresh workability of all self-compacting mortar as the content of walnut shell aggregate increases. The highest value on superplasticizer need was for SCM with 40% WS, which is 2.25 times greater for compared to CSCM.
- Self-compacting mortars based on walnut shell waste are lighter than the control SCM and can be classified as lightweight aggregate concrete (LWAC) as there dry densities are less than 2000 kg/m^3. The dry density decreases from 2162 kg/m^3 for CSCM mixe, to 1449 kg/m^3 for SCM with 40 wt. % of walnut shell/aggregate with a decrease of about 33%
- The compressive strength is reduced for all mixtures containing walnut shell waste at early and later age. The values of compressive strength at 28 days, reduced from 52 MPa for reference SCM to 26 MPa for mixture with 30% of WS, and to 14 MPa for mixture with 40% of WS.
- The addition of walnut shell aggregates increases the capillary water absorption for all SCM mixtures. The highest value was 1.9 kg/m^2 for SCM containing 40% of WS and the lowest value was 0.8 kg/m^2 for CSCM, with à reduction of about 58%. However, all SCM mixtures can be considered with good quality where their absorption values are less than 10%.
- The self-compacting mortar thermal conductivity reduces with the walnut shell waste content increase. The Thermal conductivity decreases from 1.56 W/(m.K) for CSCM to 0.63 W/(m.K) for SCM with 40ù of WS.
- Based on their thermal conductivity (λ) values less than 1 W/(m.K), SCMs with 20, 30 and 40% of walnut shell waste are considered as materials with good thermal insulation compared to conventional concrete.

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