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Development of A New Local Mineral Admixture for Enhancing Concrete properties

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Abstract

Proceeding from the saying of our God almighty on his book, the holy Qur'an: "Then ignite for me, O Hāmān, (a fire) upon the clay (From which bricks are made) and make for me a tower....". In addition to, our duty as civil engineers, we must work continually to develop cement admixtures, to reduce the negative impact during its manufacture. Therefore, this paper presents an investigation on, using calcined ball-clay (CBC) as mineral pozzolanic admixture for concrete production. CBC is obtained from calcination processes for local ball-clay at specified conditions. To evaluate ball-clay calcination process, various temperatures (600–900 ºC) and burning durations (2, 3 and 4 hours) are used and the optimum temperature and burning time for calcination are assessed by strength activity index at age of 28 days. The hardened properties development of concrete mixtures containing 0%, 10%, 15% and 20% CBC as cement partial replacement are analysed in terms of compressive strength at 7, 28, 90 and 180 days, water absorption, ultra-sonic pulse velocity and electrical resistivity. In addition, microstructure by XRD of the cement pastes incorporating CBC was studied. The results showed that the optimum calcination process to obtain CBC are carried out at temperature 800 °C for 4 hours. The replacement of cement by 10% of CBC is an optimal dosage for concrete mixtures since it achieved an increase of compressive strength by 28% as compared with control one. Therefore, adding CBC can lead to a beneficial utilization of natural local resources, which reduces energy consumption and minimizes CO_2 footprint during the manufacturing of cement concrete, thus, concrete can become an eco-friendly and sustainable material.

1. Introduction

Nowadays no one can imagine world life without concrete as a construction material. Concrete is one of the most extensively used construction materials in the world, where each year billions of tons placed worldwide. Based on the words of our God Almighty in his book the **Noble Qur'an [1]** "And Pharaoh said, "O eminent ones, I have not known you to have a god other than me. Then

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ignite for me, O Hāmān, (a fire) upon the clay (From which bricks are made) and make for me a tower that I may look at the God of Moses. And indeed, I do think he is among the liars". As is well known and very famous, **Mehta, P.K. [2]** mentioned that the use of cementing materials is very old. The ancient Egyptians used calcined impure gypsum. The Greeks and Romans used calcined limestone and later learned to add to lime and water, sand and crushed stone or brick and broken tiles. This was the first concrete in history. Many attempts worldwide in previous research to enhance the performance of blended cement-based materials lead to increased use of pozzolanic materials. A pozzolanic material is defined as a siliceous or siliceous and aluminous material, without direct cementitious value, but will, in the presence of moisture, reacts chemically with calcium hydroxide (at ordinary temperatures) to form compounds possessing cementitious properties **[3]**.

Since concrete is the most widely used construction material due to its favourable durability to cost ratio, there is a high priority in concrete technology to enhance sustainability of concrete with the partial substitution of Portland cement by supplementary cementing materials (SCMs). These materials are mostly silicate-based materials and majority of them is industrial waste. The partial substitution of Portland cement with SCMs can significantly reduce the CO_2 emission during the production of concrete and, therefore, can make concrete a more sustainable and environmental-friendly material. Some of the SCMs are silica dominated (e.g., silica fume, waste glass powder, perlite powder, quartz powder), some are aluminosilicates (e.g., activated clays, metakaolin's) and some are ternary composition of SiO2-Al2O3-CaO (e.g., slags and fly ashes). SCMs contribute to the hydration of Portland cement by physical phenomena (e.g., nucleation effect) or by chemical reactions (e.g., pozzolanic activity) **[4–15]**.

To learn more about pozzolanic materials **Erdogan, T.Y. [16]** stated that, mineral admixtures are finely divided solids which are added to concrete to improve its workability, strength, durability, economy, and to control the rate of hydration. There are two groups of mineral admixtures. The first group has pozzolanic properties and the second group doesn't have any pozzolanic properties and are also termed as fillers. A pozzolanic property is defined for materials that exhibit binding property when they are hydrated in the presence of hydrated lime so they can replace the Portland cement. Natural pozzolans, artificial pozzolans such as fly-ash and silica fume and ground granulated blast furnace slag are examples of such mineral admixtures.

The use of calcined ball-clay in production of concrete has not received adequate attention. Limited research has been conducted on this field, Cuban research by **Rancés Castillo Lara, et al. [17]** evaluated the behaviour of physical-mechanical properties and durability in micro-concretes, by employing calcinated and grinded clays as replacement material, with 30% of ordinary Portland cement (OPC). In his research, clay soil was employed, which is mainly composed by low-purity-kaolin mineral, to obtain calcined clays to be used as supplementary cementitious minerals. Best results for compressive strength at 28 days were obtained by sedimentary calcined clays, which have higher content of kaolin mineral. Recently, **Sharma, Meenakshi, et al [18]** reviews the rapidly developing state of the art literature available about the recently developed limestone calcined clay cement (LC3). The used calcined clay was three types of metakaolin. An introduction to the background leading to the development of LC3 is first discussed. The chemistry of LC3 hydration and its production are detailed. The influence of the properties of the raw materials and production conditions are discussed. The mixture design of concrete using LC3 and the mechanical and durability properties of LC3 cement and concrete are then compared with other cements. At the end the economic and environmental aspects of the production and use of LC3 are discussed. The paper ends with suggestions on subjects on which further research is required.

To our knowledge, it can be said that there is no polished research on the potential of local CBC for use as mineral pozzolanic admixture. So, the current research investigates the influence of incorporating CBC obtained from thermal treatment of local ball-clay at various cement replacement level on properties of fresh and hardened concrete and compares these properties with those of available commercial fly ash (FA) and control concrete ones.

2. Experimental Work

2.1 CBC Producing

There are three main minerals on kaolinite clays family, these minerals differ in crystalline composition, physical properties, granular size, and impurities, despite of their similarity in the basic chemical composition of Al4Si4O10(OH)8, These minerals are kaolin, ball-clay, and refractory or igneous clay, which is locally called "Aswanly clay".

Locally, ball-clays (BC) are exploited from the areas of Abu Al-Rish Kibly, Abu Al-Rish Bahry and Abu Sabira north of Aswan, where they spread in large quantities in an area of 70 km2 and thickness from 2 to 4 meters. The Egyptian Company for Refractories exploits the clay extracted from its mines in Abu Sabira in the production of refractories, and it is marketed under the name "Masria 32, 30". Ball-clay is currently used in the manufacture of sewage bricks, pipes, and pottery products. After processing this material and reaching an appropriate proportion of ferric oxide, it can be safely used in the production of refractories and ceramic, porcelain, and China tiles due to its high plasticity that helps to facilitate its formation.

To activate raw local BC and convert to CBC by thermal activation (calcination) and considers CBC like metakaolin, which is obtained from the thermal calcination of kaolin clay (Al2Si2O5(OH)4). Calcination is a term referring to the controlled burning process at a specific temperature range to obtain a quasi-amorphous material. The range of burning temperature is usually in 650-850ºC to create an amorphous aluminosilicate that is reactive in concrete. This thermal treatment activation or dihydroxylation, leads to the breakdown or partial breakdown of the crystal lattice structure, forming a phase transition which is highly disordered, amorphous and with pozzolan city. To find out if there is a benefit from activating ball-clay BC and converting it into calcined ball-clay (CBC) as a pozzolanic material, sample of BC was supplied from Abu Sabira, Aswan, Egypt. The samples of BC were grounded on the rotary mills on one of the local companies to get suitable fineness about 60 µm. To verify the disappearance of the characteristic peaks of kaolinite, the mineral analysis of raw BC was performed by X-ray diffraction (XRD). Result of x-ray diffraction test of BC are presented in Fig. 1. Also, to clarify the chemical characteristics of raw BC, the chemical analysis by X-ray fluorescence test is carried out and given in Table 1.

To produce CBC, samples of BC were calcined at controlled burning process by a laboratory furnace. Calcination was conducted in Ceramic crucibles with Diameter: 300 mm; Height: 80 mm and were reinforced by steel frame from outside. The reason for using ceramic crucibles because, ceramic is an inert material, does not react with the BC and withstands temperature of calcination successfully. To evaluate calcination processes, various temperatures (600, 700, 800 and 900 ºC) and burning durations (2, 3 and 4 hours) are used. Optimum temperature and burning time for calcination are assessed based on strength activity index at age of 28 days. Strength activity index (SAI) is in accordance with ASTM C311[19] and is defined as the ratio between the mortar compressive strength of two specimens, the mortar with 20% admixture (by weight substitution) and the control mortar (0% admixture).

Table 1. The chemical analysis of raw ball- clay (BC).

Chemical compositions. %	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**TIO_2**	**K_2O**	**Na_2O**	**SO_3**
BC	58.8	25.7	9.4	0.96	0.16	3.78	0.46	0.09	0.2

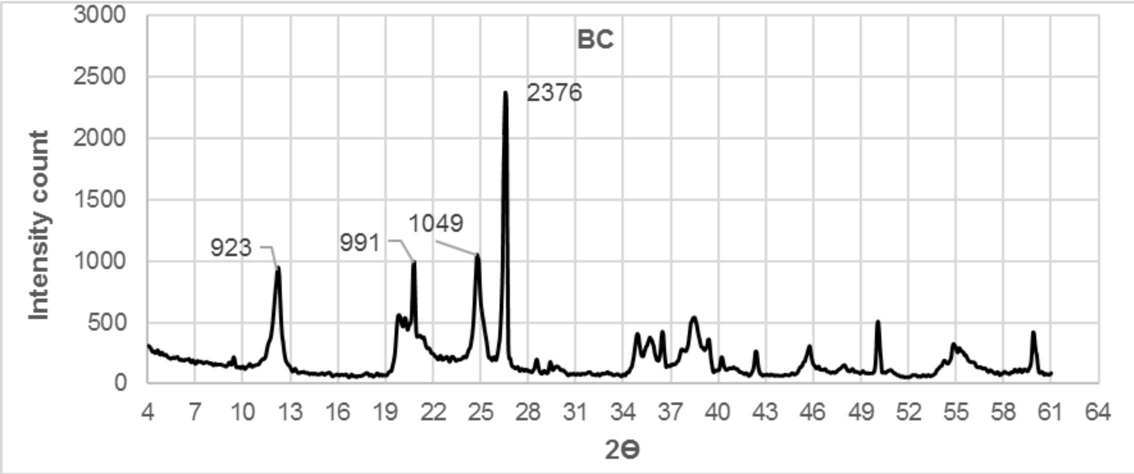


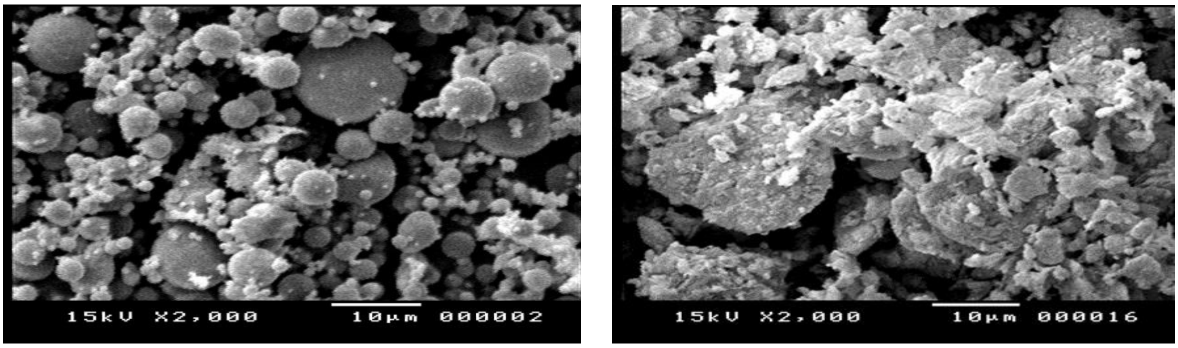
Fig. 1 X-ray diffraction test results of raw ball- clay (BC).

2.2 Materials and Mixture Proportions

After a proper thermal calcination calcined BC (CBC) were obtained, and its chemical compositions and physical properties are presented in Table 2. Commercially imported Class F fly ash (FA) (conforming to **ASTM C618 [3]**) was also used for comparison. FA chemical compositions and physical properties are summarized in Table 2. Furthermore, a detailed description of microstructural of CBC and FA using scanting electronic microscope (SEM) are shown in Fig. 2.
An Ordinary Portland Cement OPC (CEM I 42.5 N) with specific gravity of 3.12 and having Blaine fineness of 3470 cm^2/gm was used in all tested concrete and mortar mixtures. Chemical analysis of this cement is shown also in Table 2. The used aggregates on this paper were obtained from local sources. The fine aggregate was clean natural siliceous sand having water absorption of 0.73%, fineness modulus of 2.42 and a specific gravity of 2.55. The used coarse aggregate was natural gravel with maximum nominal size of 40 mm and have a specific gravity, crushing value and water absorption of 2.5, 11.75 and 0.58%, respectively. The fine aggregate Sand to gravel ratio (S/G) was kept constant at 0.60 for all tested concretes. The trade name of used Super-plasticizing admixture is ADDICRETE B-V-F which is a high range water-reducing admixture with specific gravity of 1.19 was utilized to achieve a slump of 10± 2 cm in all concrete mixtures. The superplasticizer was modified at the time of mixing to achieve the target slump.

Table 2. Chemical composition and Physical properties of used cement and SCMs

	Chemical composition (%)									**Physical properties**		
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**TIO_2**	**K_2O**	**Na_2O**	**SO_3**	**Specific gravity**	**Blaine (cm^2/gm)**	**colure**
OPC	22.3	3.82	3.50	62.6	1.40	--	0.24	0.4	2.54	3.15	3732	Gray
CBC	59.1	25.9	9.5	0.98	0.16	3.78	0.46	0.09	0.2	2.40	4143	yellowish white
FA	43.50	27.3	7.90	10.6	2,77	1.7	0.92	0.53	1.43	2.20	4340	Light gray



(a) (b)

Fig. 2 SEM micrographs of (a) FA and (b) CBC.

Concrete mixtures were designed at constant 0.4 water/binder (w/b) ratio and having a constant total binder (cement + SCMs) content of 400 kg/m3. The percentages of CBC that replace OPC were 10%, 15% and 20% by weight of cement, while three replacement levels (15%, 20%, and 30%) of FA were for compression. On the other hand, one plain mix without admixture was employed as control. Details of the mixtures are presented in Table 3. Casting of concrete cubes was carried out in two layers. Each layer was compacted to achieve good compaction and to minimize the air voids. After casting, the concrete specimens were covered with a wet towel and kept under laboratory conditions. After 24 hours they were demolded and cured in water tank at laboratory conditions.

Mortar mixes were prepared according to the **ASTM C311, [19]** where the proportions (binder: sand) was 1:3, water/binder (w/b) ratio was around at 0.484, superplasticiser (SP) was added by 1.5 % of binder weight to obtain a constant workability.

2.3 Test Methods

2.3.1 Compressive strength test

The cubic concrete specimens with dimension of 15*15*15 cm were tested for compressive strength after 7, 28, 90 and 180 days of curing with water. Three specimens were tested for each age and the mean value of these measurements was reported.

Table 3. Mix proportions of concrete mixtures.

Mix cod	OPC Kg/m^3	W/c	Water Kg/m^3	Repla-cment ratio	CBC Kg/m^3	FA Kg/m^3	Gravel Kg/m^3	sand Kg/m^3	Slump cm	Super-plast L/m^3
PC	400	0.40	160	--	--	--	1114	668	9	2.65
FA15	340	0.40	160	15 %	--	60	1101	661	11	4.45
FA20	320	0.40	160	20 %	--	80	1097	658	9	5.10
FA30	280	0.40	160	30%	--	120	1089	653	10	7.28
CBC10	360	0.40	160	10%	40	--	1108	665	9	4.72
CBC15	340	0.40	160	15%	60	--	1105	663	12	5.80
CBC20	320	0.40	160	20 %	80	--	1101	660	8	7.37

2.3.2 Water absorption test

Three specimens from each examined concrete mixes were utilized for water absorption tests. After the end of the 28-day curing time, concrete specimens were dried at 105˚C until reaching constant weight after that cooled at room temperature, weighed using an electronic scale (W_1). Afterwards they were immersed into the water tank for 24 hours then the surface was dried and then weighed again (W_2). The value of % water absorption was computed using the following equation.

$$\% \text{ Water absorption by weight} = (W_2-W_1)/W1*100 \quad (1)$$

2.3.3 Electrical surface resistivity (SR) test

The Electrical Surface Resistivity (SR) of the concrete specimens were measured by electrical resistivity meter. This non-destructive laboratory test method measures the electrical resistivity of dried concrete and provides an indication of its permeability. The test result is a function of the electrical resistance of the specimen. The cubic 15*15*15 concrete specimens of each examined mixtures at the age of 28 days were tested. Before testing the two opposite sides of the tested specimens they must be covered with graphite, to enable readings by resistivity meter. The electrical surface resistivity testing set-up is shown in Fig. 3.

2.3.4 Ultrasonic pulse velocity test

The ultrasonic pulse velocity of each concrete mix series was measured using three cubes' specimens after a curing period of 28 days. The testing equipment used was the PUNDIT from C.N.S. ELECTRONICS LET London England. The outer surface of both ends of the cubic was cleaned and then a couplant was applied. This was done to ensure that the transducers maintained full contact to the cubic during testing. Once the main menu appeared, the concrete cubic was placed with a transducer on either end making sure that full contact was achieved. To achieve full contact, the sides of the specimen should be coated with grease. The test was started by sending the wave from one transducer and receiving it on the other side of the specimen by the other transducer. The output from the testing device was the velocity of the wave computed by dividing the specimen length by the time of transmission. The ultrasonic pulse velocity testing set-up is shown in Fig. 4.

Fig. 3 Experimental Set-up for Electrical Surface Resistivity Testing

Fig. 4: Experimental Set-up for Ultrasonic Pulse Velocity Testing

2.3.5 X-ray diffraction (XRD)

To examine the crystallography of the hardened bonding materials, X-ray Diffraction (XRD) analysis was performed to find out the hydrated products at age 28 days of cement paste samples. Samples were derived and prepared from the hardened cement paste of crushed specimen of each tested concrete mix.

3. Results and Discussion

3.1 Strength activity index (SAI) results

To evaluate ball-clay calcination processes, optimum temperature and burning time for calcination are assessed based on strength activity index at age of 28 days. The obtained SAI is shown in Fig. 5. This figure clearly shows that after heat treatment at 600–900 ºC for 2, 3 and 4 h, the pozzolanic activity was increased significantly. The raw BC showed a decrease of the activity index at 28 days because such unprocessed BC may act as a micro filler only and not able to react with portlandite Ca (OH)2 (CH) Thus, it leads to a decrease in compressive strength. Based on the obtained results, the optimum SAI is achieved for BC calcined at 800 ºC for 4 h. The obtained SAI values for calcined BC are higher than that required by the **ASTM C 618 standard [3]**, largely fulfilling the minimum requirement of 75%, for pozzolanic materials.

3.2 Concrete compressive strength results

The compressive strength of concrete is one of the most important characteristics which, is used to judge the quality of concrete and depends on many factors that must be controlled during concrete production. These factors include the used material quality and properties to the casting and curing procedures. So, in this study the cubic (15*15*15) cm3 compressive strength of the used concrete mixtures at ages of 7, 28, 90 and 180 days have been investigated and the compressive strength values are given in Table 3.

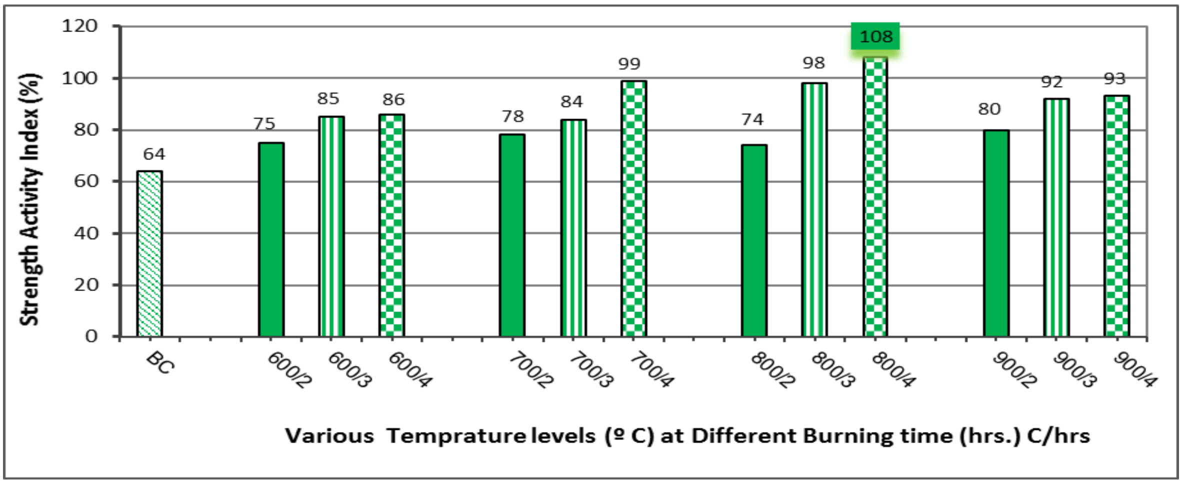


Fig. 5: Results of strength activity index for BC and calcined BC.

Table 3. Compressive strength results for all tested concrete mixtures.

Mix code	Cubic compressive strength (kg/cm^2)			
	7-days	**28-days**	**90-days**	**180-days**
PC (control, 0%)	308	370	395	405
CBC10%	335	474	522	577
CBC15%	315	420	460	473
CBC20%	290	390	423	443
FA15%	342	484	491	503
FA20%	418	522	563	592
FA30%	318	449	478	488

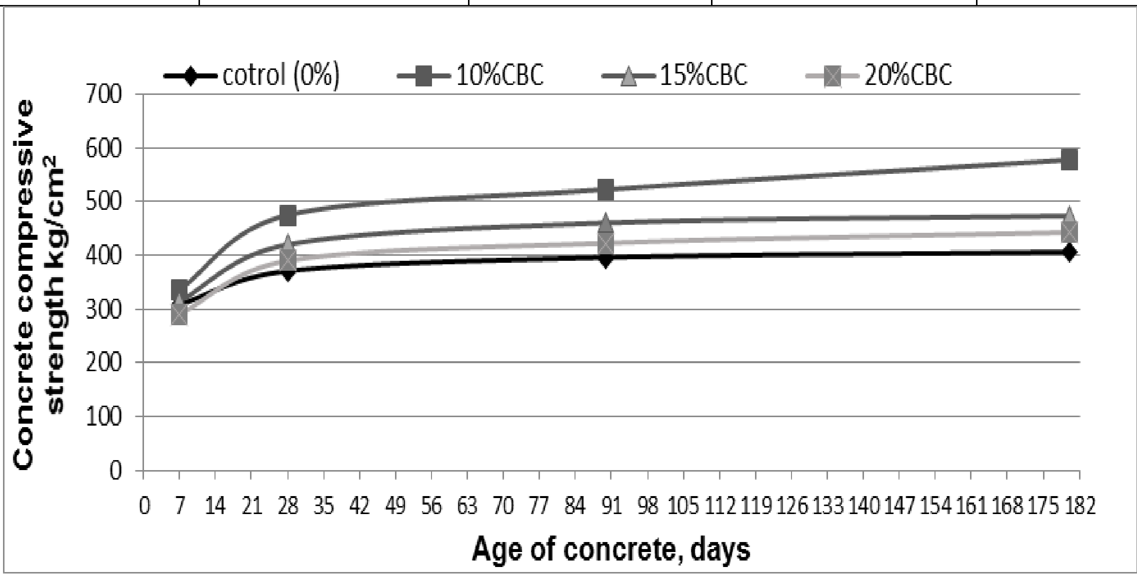


Fig. 6: Effect of calcined ball-clay, CBC% as partial replacement of OPC on concrete compressive strength.

The compressive strengths of concrete mixtures containing various ratios of CBC as replacement by weight of OPC are shown in Fig. 6. As expected, it was found that the rate of increasing of compressive strength develops with the age of concrete curing. CBC concretes have a higher compressive strength at different ages up to 180 days as compared to OPC concrete. The CBC concretes at 28 days age were higher than that of the control by about 28.11%, 13.51% and 5.41% for CBC10%, CBC15% and CBC20%, respectively. So, by increasing the replacement dosage of

CBC, the rate of increase in compressive strengths decreases. it can be observed that, the optimum CBC replacement level was 10% by weight of cement, it gives the best result when compared to other tested replacement levels, concrete mixture CBC10% is achieving an increase in the compressive strength at 7, 28, 90 and 180 days by 8.8%, 28.1%, 32.2% and 42.2%, respectively compared with control mixture.

Fig. 7 shows the compressive strength gain of FA concrete mixtures with time and illustrates the effect of various dosages of FA (0%, 15%, 20% and 30%) as partial replacement of OPC by weight. The most important observation can be concluded from Fig. 7 that, the optimum ratio of FA which gives the maximum compressive strength is 20%, with an increase in compressive strength of 36%, 41%, 43% and 46% after 7, 28, 90 and 180 days respectively, comparing to that of control concrete mixture.

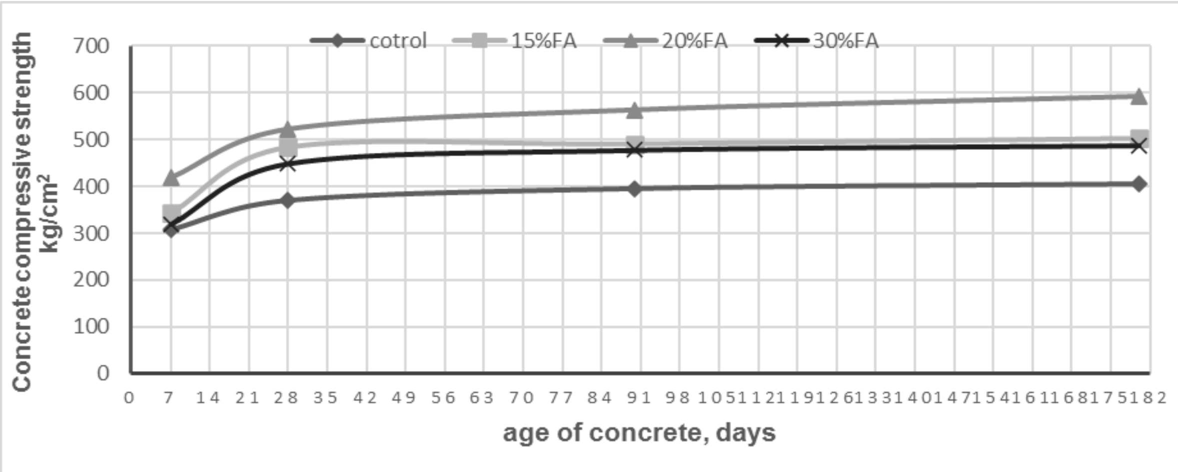


Fig. 7: Effect of fly ash, FA% as partial replacement of OPC on concrete compressive strength.

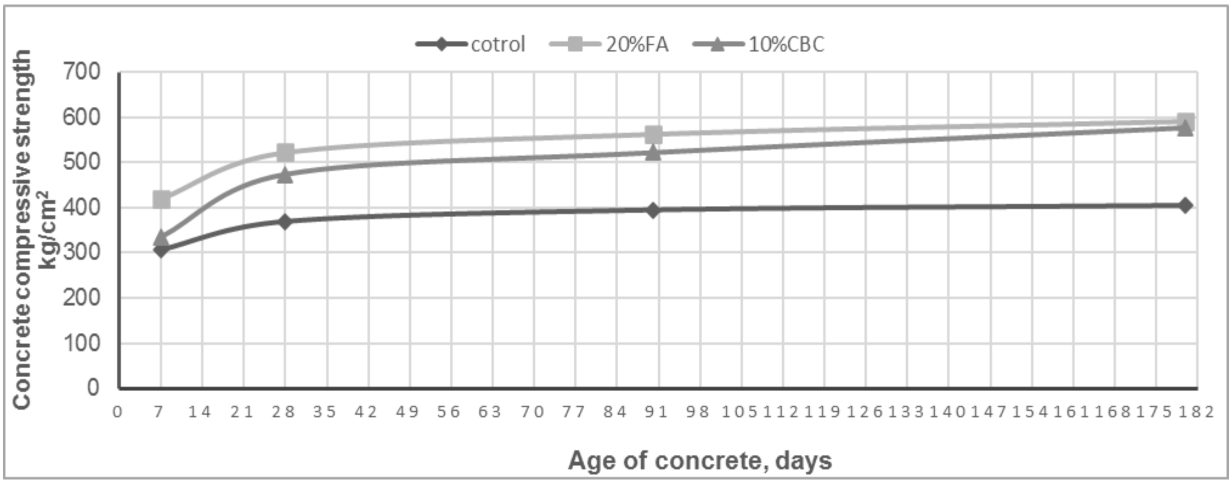


Fig. 8. Comparison between effect of (CBC), and (FA)) at optimum replacement ratio on compressive strength after 7, 28, 90 and 180 days.

To assess effect of adding CBC, Fig. 8. illustrates a comparison between effect of the optimum ratios of FA and CBC on concrete compressive strength after several ages of curing 7, 28, 90 and 180 days. it is clearly evident that, similar to FA, CBC has a positive effect on compressive strength after all ages of curing. In addition, it should be noted that, the development rate of compressive strength of CBC concrete mixtures is increased by increasing the ages of concrete but, the CBC increase rate was less than that of FA concrete mixtures. This improving on compressive strength of concretes containing either FA or CBC might be attributed to filler effect as well as, the pozzolanic reaction with free calcium hydroxide (CH) resulted in the creation of more CSH, which fill the internal capillary pores and make the structure more uniform and denser than that of control concrete.

3.3 Water absorption test results

The effect of CBC and FA content on water absorption of the examined concrete mixtures as a function of replacement level % is shown in Fig. 9. As seen, the water absorption decreases with increasing the amount of both CBC and FA content until reaching the optimum ratio, then the water absorption begins to increase. The highest value of water absorption was obtained for the control mix (without admixture). Concrete mixtures containing 10% and 15% of CBC had water absorption lower than that of FA, but the mix modified with 20% FA recorded lowest water absorption value, it recorded a water absorption decrease by about 37% while the optimum mix CBC15% had a decrease about 27%. The significant reduction in water absorption is attributed to the increase of the solid volume and the microstructure improvement. CBC as FA fill the interface between aggregates and cement paste and in the pores between cement grains. This resulted in a compact structure leading to the mitigation of water penetration inside the hardened concrete. These obtained results are consistent with what has been repored in the literuture by **M. Emerson [20].** Who concluded that, the durability of cement and concrete structures is closely related to the water absorption so the reduction of water absorption will extend the lifetime of cement-based products and hence durability.

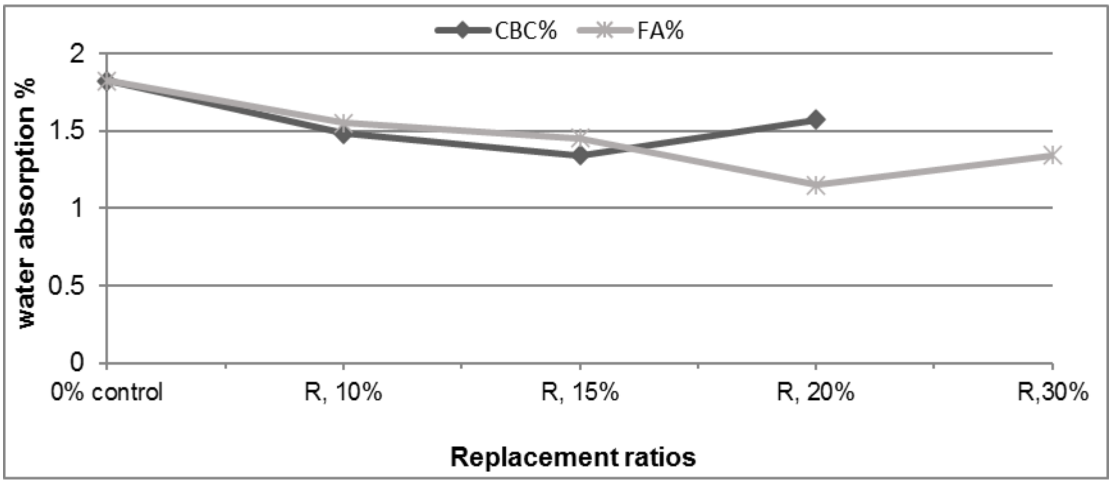


Fig. 9. Concrete water absorption% at different Replacement ratios of CBC and FA.

3.4 Electrical surface resistivity (SR) results

Electrical Surface resistivity of concrete (SR) demonstrates transmission ions (such as chloride ions) in pore solution. Concrete resistivity depends on both the microstructure properties of the concrete and the conductivity of the pore solution. SR test is a compatible indicator for concrete penetration and chloride ion permeability. In adition to, it is a non-destructive, simple, quick and low-cost method that can also be applied on site.

Fig. 10. presents results of the Surface electrical resistivity tests. It can be observed from Fig. 10. that, using CBC as FA enhances the electrical resistivity compared to control (0%) concrete. The electrical resistivity for FA% concretes increases with increasing the replacement ratio, while when CBC% replacement ratio increases up to 15% the concrete electrical resistivity increases after that it starts to decrease. The highest value of electrical resistivity is 730 kΩ for the FA30% mixture after 28 days at about 3 times higher than that for control one. The best replacement ratio of CBC% was 15%, which achieved an increase in electrical resistivity about towice up than that for the control

mixture. This result confirms our findings that, cement replacement with CBC by 10% is the optimum ratio in the concrete compressive strength.

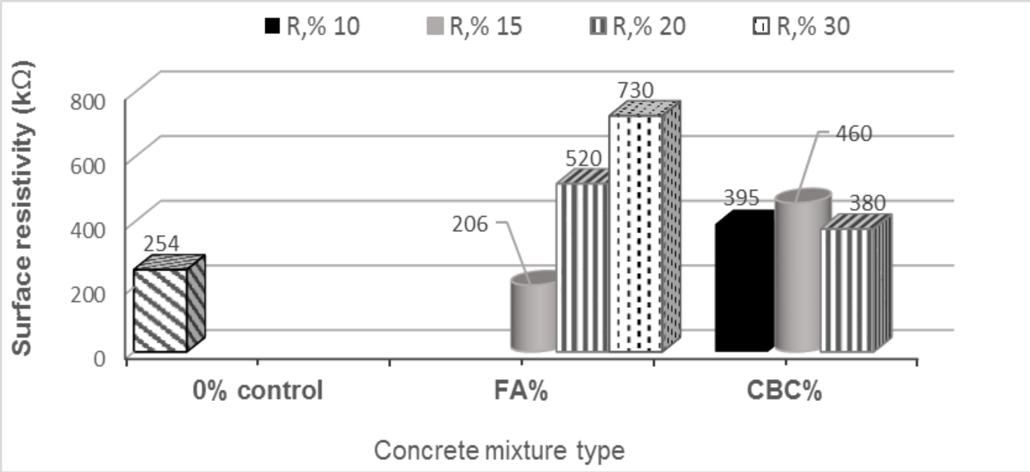


Fig. 10. The effect of FA% and CBC% on concrete Surface electrical resistivity after 28 days of age.

3.5 Ultrasonic pulse velocity test results

Ultrasound pulse velocity test is one of the favored non-destructive methods for foretelling concrete quality. More than that, this test can be performed without breaking the tested samples and using them in other tests.

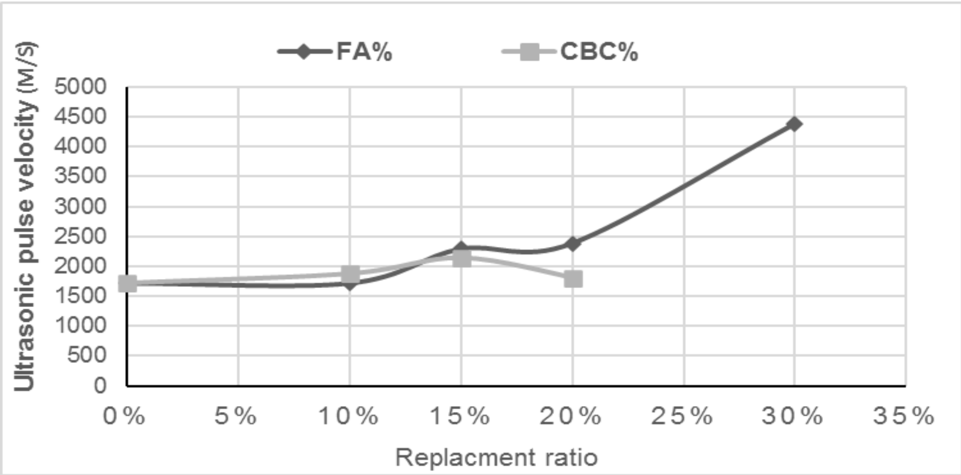


Fig. 11. The effect of FA% and CBC% on concrete ultrasonic pulse velocity at age of 28 days.

It was clear from Fig. 11, as the FA content was increased the ultrasonic pulse velocity also increased moderately. Concrete with 0% admixtures (control) yielded the lowest values of pulse velocity, and 30% FA yielded the highest velocities. As for CBC concrete mixtures, it can be clearly observed that the pulse velocity increases with the CBC content increased up to 15% of CBC then the pulse velocity begins to decrease. The results of the ultrasonic pulse velocity test agree with the results of electrical resistivity test, whereas the optimum cement replacement ratio of CBC is 15% and for FA is 30%, which are exhibited the better performance on both of tests. These results confirm with the general predictions that pulse velocity and surface electrical resistivity are an indirect method of testing the quality of a concrete.

3.6 X-ray diffraction (XRD) test results

Hardened cement pastes samples from crashed concrete specimen of selected concrete mixtures after 28 days were used for X-ray diffraction studies. The XRD patterns for the ordinary Portland cement pastes without admixtures and cement pastes with 15% of CBC and 30% of FA are plotted in Figs.12, 13, and 14, respectively. From these Figs, it can be observed that extremely intensive peaks of Quartz are visible in all the XRD patterns. Moreover, the peaks of Quartz in both of 15%CBC and 30%FA are significantly larger than that of OPC paste. On the other hand, the amount of portlandite (Ca (OH)2) phases in the CBC and FA cement pastes was lower than in the OPC paste. So, substitution CBC on concrete as FA have resulted in reducing in the calcium hydroxide (CH) diffraction peaks. The comparison between the diffractograms of cement pastes detects that the addition of 15% CBC as cement replacement leads to the reduction of intensity count of maximum peak of calcium hydroxide from 614 to 304 at 28 days while, cement substitution ratio by 30% FA leads to reduce intensity count to 173. From these results, it can be concluded that CBC like FA reacts with calcium hydroxide due to a pozzolanic reaction, resulted in producing calcium silicate hydrates and calcium aluminosilicate hydrates.

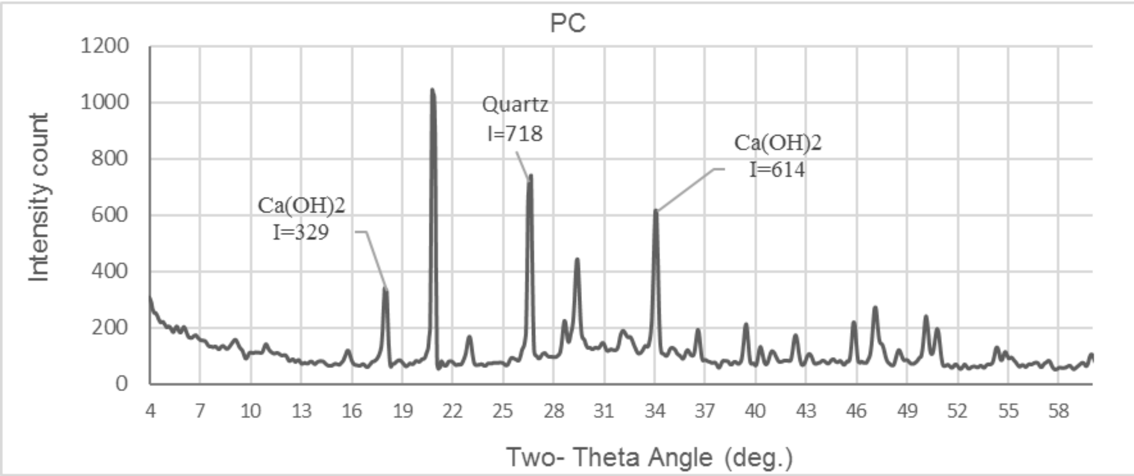


Fig. 12. XRD patterns of OPC paste without admixtures after 28 days.

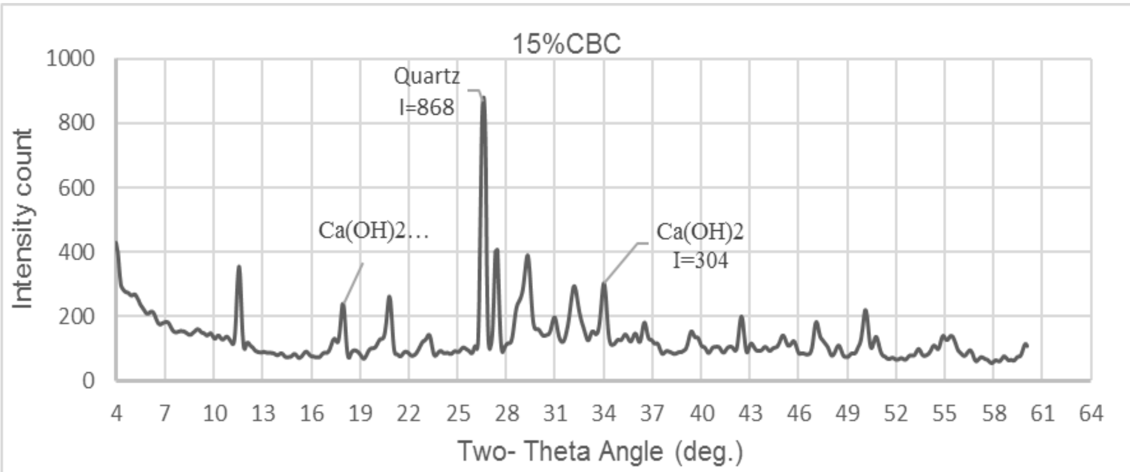


Fig. 13. XRD patterns of OPC paste with 15% of CBC after 28 days of age.

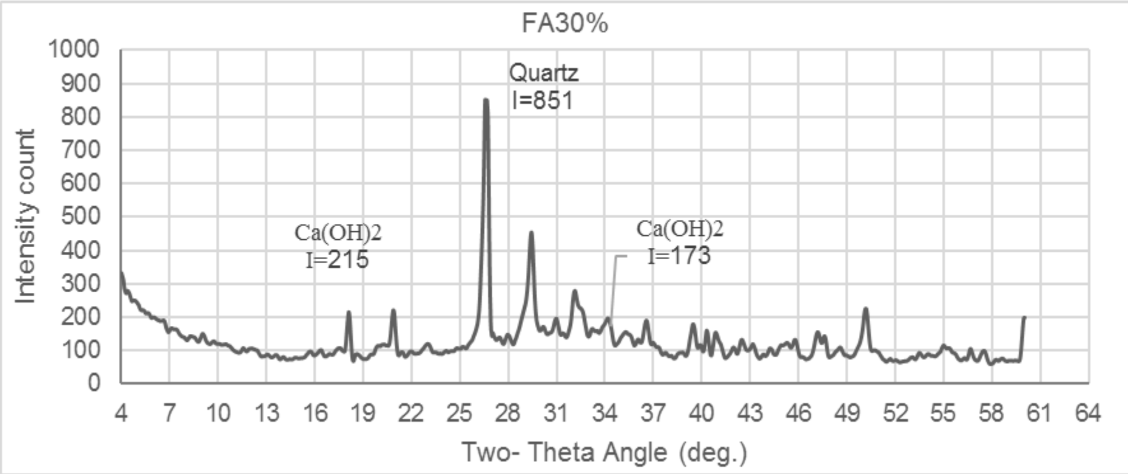


Fig. 14. XRD patterns of OPC paste with 30% of FA after 28 days of age.

4. Conclusion

In this research, the effect of local calcined ball clay as supplementary cementing materials and mineral pozzolanic materials as well as, comparing its effect with that of fly ash on performance of concrete. From the results obtained in this study, the following conclusions can be drawn out.

- Calcination process at the optimal conditions 800 ºC for 4 h is efficient for the conversion of raw ball-clay to calcined ball-clay (CBC). At these conditions, the obtained CBC exhibits the highest strength activity index.
- Calcined ball-clay (CBC), which was derived from unprocessed local ball-clay, provided similar behavior to that of the commercial fly ash, with respect to the studied parameters, concrete compressive strength development, water absorption, surface electrical resistivity and ultra-sonic velocity.
- The incorporation of calcined ball-clay (CBC) into concrete mixtures increased the compressive strength due to its filling and pozzolanic effects. The cement replacement by 10% of CBC can enhance the 7-, 28-, 90- and 180-days compressive strength by 8.8%, 28.1%, 32.2% and 42.2% respectively, as compared to control ones.
- Surface electrical resistance and ultra-sonic velocity of concretes with calcined ball-clay exhibited higher values than those of the control concrete. While surface electrical resistance of concretes with fly ash displayed the highest values compared to those of both the control and calcined ball-clay concrete mixes.
- Addition of calcined ball-clay like fly ash provided an enhancement in concrete microstructure due to a pozzolanic reaction and results in the formation of well compacted dense structure.
- The results of study showed that optimal CBC concrete performance was achieved at partial cement replacement by 10% of CBC regarding compressive strength while, by 15% regarding both of surface electrical resistance and ultra-sonic velocity testes.
- Local calcined ball-clay is an active pozzolanic supplementary cementing materials that can be used in the production of concrete. It has a positive effect on the mechanical properties of cement concretes without affecting the effectiveness of cement and its mechanical properties.
- The addition of CBC can lead to a beneficial utilization of natural local resources, which reduces energy consumption and minimizes CO_2 footprint during the manufacturing of cement concrete, thus, concrete can become an eco-friendly and sustainable material.

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تطوير إضافة معدنية محلية جديدة لتحسين خواص الخرسانة

الملخص العربي:

انطلاقاً من قول ربنا عز وجل في كتابه القرآن الكريم: (وَقَالَ فِرْعَوْنُ يَٰٓأَيُّهَا ٱلْمَلَأُ مَا عَلِمْتُ لَكُم مِّنْ إِلَٰهٍ غَيْرِي فَأَوْقِدْ لِي يَٰهَٰمَٰنُ عَلَى ٱلطِّينِ فَٱجْعَل لِّي صَرْحًا لَّعَلِّيٓ أَطَّلِعُ إِلَىٰٓ إِلَٰهِ مُوسَىٰ وَإِنِّي لَأَظُنُّهُۥ مِنَ ٱلْكَٰذِبِينَ). وبالإضافة إلى واجبنا نحن المهندسين المدنيين، يجب أن نعمل باستمرار على تطوير إضافات للأسمنت للتقليل من التأثير السلبي الناتج أثناء تصنيعه .لذلك، هذا البحث يقدم تحقيقا حول استخدام طين البو لكلى المحلى المكلس (CBC) كإضافة معدنية بوزولانية لإنتاج الخرسانة. حيث يتم الحصول على CBC من عمليات التكليس لطين البولكلى المحلي في ظروف محددة. ولتقييم عملية تكليس طين البولكلى، تم استخدام درجات حرارة مختلفة (٦٠٠-٩٠٠ درجة مئوية) ومدد حرق (٢ و٣ و٤ ساعات) وتم تقييم درجة الحرارة المثلى وزمن الاحتراق للتكلس من خلال مؤشر نشاط القوة في عمر ٢٨ يومًا. تم دراسة خصائص الخلطات الخرسانية التي تحتوي على نسب ٠ ٪ و١٠٪ و١٥٪ و٢٠٪ من CBC كبديل جزئي للأسمنت من حيث مقاومة الانضغاط عند ٧ و٢٨ و٩٠ و١٨٠ يومًا وامتصاص الماء وسرعة النبض فوق الصوتي والمقاومة الكهربائية. بالإضافة إلى ذلك، تمت دراسة البنية المجهرية بواسطة XRD لمعاجين الأسمنت التي تحتوي على .CBC أظهرت النتائج أن عملية التكليس المثلى للحصول على CBC تتم عند درجة حرارة ٨٠٠ درجة مئوية لمدة ٤ ساعات. يعتبر استبدال الأسمنت بنسبة ١٠٪ من CBC جرعة مثالية للخلطات الخرسانية حيث إنها حققت زيادة في مقاومة الانضغاط بنسبة ٢٨٪ مقارنةً بالتحكم. ولهذا يمكن أن تحقق إضافة CBC استخدامًا مفيدًا للموارد المحلية الطبيعية، مما يوفر استهلاك الطاقة ويقلل من انبعاثات ثاني أكسيد الكربون أثناء إنتاج الخرسانة الأسمنتية، وبالتالي، يمكن أن تجعل الخرسانة مادة مستدامة وأكثر صداقة للبيئة.